AD-A116 952 ILLINOIS UNIV AT URBANA DEPT OF ELECTRICAL ENGINEERING F/G 9/5
A FORTRAN PROGRAM FOR RECTANGULAR MICROSTRIP ANTENNAS.(U)
APR 82 W F RICHARDS, Y T LO AFOSR-81-0234
UNCLASSIFIED UILU-ENG-80-2538 RADC-TR-82-78 NL

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RADC-TR-82-78

Rept. Nos. EM 80-1, UILU-ENG-80-2538

Interim Rept.

Apr. '82

DOCUMENT IDENTIFICATION

AFOSR Grant 81-0234

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4. TITLE (and Subtitle) A FORTRAN PROGRAM FOR RECTANGULAR MICROSTRIP ANTENNAS		5. TYPE OF REPORT & PERIOD COVERED Interim Report
		6. PERFORMING ORG. REPORT NUMBER EM 80-1 UILU-ENG-80-2538
7. AUTHOR(s) W. F. Richards Y. T. Lo		8. CONTRACT OR GRANT NUMBER(s) AFOSR Grant - 81-0234
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11. CONTROLLING OFFICE NAME AND ADDRESS Deputy for Electronic Technology (RADC/EEAA) Hanscom AFB MA 01731		12. REPORT DATE April 1982
		13. NUMBER OF PAGES 84
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Same		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer: John A. Strom (EEAA)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Microstrip Antennas
Excitation of Cavity and Input Impedance
Multiport Microstrip Antennas
Circularly Polarized Microstrip Antennas
Microstrip Analysis Program

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This report supplies a program, with examples, for the analysis of rectangular microstrip antennas. The formulas upon which the program is based are also provided. The theory from which these formulas were obtained is based on the "cavity model" of the microstrip antenna developed at the University of Illinois by Lo, Richards, et al. Details of the theory can be found in the references listed in the bibliography at the end of the report.

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The first chapter contains the formulas and the definitions of the electrical and geometrical parameters used in the program. Chapter two lists the FORTRAN program which implements these formulas. Chapter three contains examples of the program's use. It includes an example which illustrates the use of the two-port analysis feature of the program to determine the "tuning range" that a variable capacitor loading one port would have to have in order for the radiator to produce any polarization from left hand circular to right hand circular.

This report has been reviewed by the RADC Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RADC-TR-82-78 has been reviewed and approved for publication.

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Project Engineer

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Acting Chief, Plans Office

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INTRODUCTION

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CHAPTER 1: FORMULAS AND DEFINITIONS

For completeness, the basic formulas and procedures used to compute the pattern and impedance of a microstrip antenna are reviewed. The geometrical parameters used in the formulas that follow are defined in figure 1.

I GENERAL NOTATIONS

The following notations are used in the formulas within this appendix.

(1) $k_0 = 2\pi f/c$ where f is the frequency and c is the speed of light in free space.

(2) $\eta_0 = 377\Omega$.

(3) $\epsilon_{0m} = 1$ for $m = 0$ and 2 otherwise.

(4) (r,θ,ϕ) is the coordinate of a point in spherical coordinates. The direction perpendicular to the ground plane corresponds to $\theta = 0$. The line $\theta = \pi/2$, $\phi = 0$ is the x axis while $\phi = \pi/2$ is the y axis.

(5) $p_m = (k^2 - (m\pi/a)^2)^{1/2}$ (the branch is irrelevant).

(6) $k = k_0\epsilon_r^{1/2}(1-j\delta)^{1/2}$ where the branch is also irrelevant, ϵ_r is the relative dielectric constant of the dielectric substrate, and δ is the loss tangent of the dielectric substrate (later to be replaced by the "effective loss tangent." See V.)

(7) $\Phi_m^{(1)} = \left\{\dfrac{\epsilon_{0m}}{a}\right\}^{1/2} \cos[p_m(b-y)]\cos(m\pi x/a)$, for $y \geqslant y_1$, and

$\Phi_m^{(2)} = \left\{\dfrac{\epsilon_{0m}}{a}\right\}^{1/2} \cos(p_m y)\cos(m\pi x/a)$, for $y < y_1$.

(8) $j_0(x) = \sin(x)/x$ (the spherical Bessel function of zero order).

(9) Δ is the skin depth.

II PATTERN AND RADIATED POWER

Radiated power, P_{rad}, is computed in subroutine VRAD. This routine calls the double integration routine, VDOUBL, which applies 4-point Gaussian quadrature recursively to integrate the power pattern supplied by VPPAT. The function VPPAT calls VPAT which computes the complex polar pattern of the antenna by application of the following formulas:

$$\mathbf{F} = -\frac{e^{-jk_0 r}}{r}\frac{jk_0 t\eta_0 b}{2\pi}\sum_{m=0}^{\infty}\frac{\epsilon_{0m}\cos(m\pi x_1/a)}{p_m b\sin(p_m b)} j_0\left(\frac{m\pi d}{2a}\right)\left[(-1)^m e^{jk_0 a\sin\theta\cos\phi} - 1\right]$$

$$\cdot\left\{\hat{x}\left[\cos(p_m y_1)e^{jk_0 b\sin\theta\sin\phi} - \cos[p_m(b-y_1)]\right]\frac{jk_0 a\sin\theta\cos\phi}{(m\pi)^2 - (k_0 a\sin\theta\cos\phi)^2}\right.$$

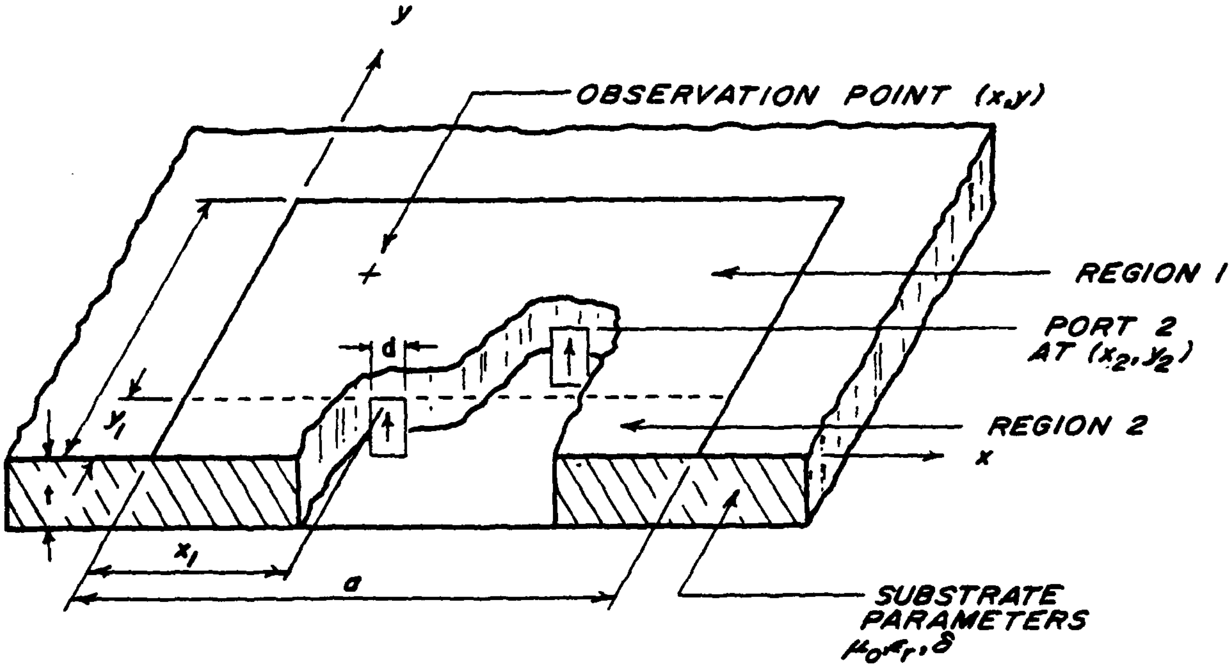


Figure 1. Geometry and Idealized Feeds for the Rectangular Microstrip Antenna

$$- \hat{y}\frac{b}{a}\Big[p_m b\sin(p_m b)\, e^{jk_0 y_1 \sin\theta\sin\phi} + jk_0 b\sin\theta\sin\phi$$

$$\cdot \Big[\cos(p_m y_1)\, e^{jk_0 b\sin\theta\sin\phi} - \cos[p_m(b-y_1)]\Big]\Big]$$

$$\cdot \Big[(p_m b)^2 - (k_0 b\sin\theta\sin\phi)^2\Big]^{-1}\Big\}$$

$$E_\theta = k_0(-F_x\sin\phi + F_y\cos\phi)$$

$$E_\phi = -k_0(F_x\cos\phi + F_y\sin\phi)\cos\theta$$

where E_θ and E_ϕ are the θ and ϕ components of the electric far field, F_x and F_y are the x and y components of $\mathbf{F}$, and $\hat{x}$ and $\hat{y}$ are the unit vectors in the x and y directions.

III STORED ENERGY AND OHMIC LOSSES

The stored electric energy, W_E, is computed from

$$4\pi f W_E = \epsilon_r k_0 t (k_0 b)^2 \eta_0 \sum_{m=0}^{\infty} \frac{j_0^2\left(\dfrac{m\pi d}{2a}\right)}{\left|p_m b\sin(p_m b)\right|^2}$$

$$\cdot \left\{ y_1 \left|\Phi_m^{(1)}(x_1,y_1)\right|^2 N(p_m y_1) + (b-y_1)\left|\Phi_m^{(2)}(x_1,y_1)\right|^2 N[p_m(b-y_1)] \right\},$$

where

$$N(z) = \frac{1}{2}[j_0(j2\mathrm{Im}z) + j_0(2\mathrm{Re}z)].$$

The dielectric loss is found from

$$P = 4\pi f \delta W_E.$$

The copper loss is determined using

$$\frac{P_{Cu}}{P_d} \approx \frac{\Delta}{\delta t}$$

(at resonance). All these quantities are computed within subroutine VENLS.

IV IMPEDANCE

The impedances are computed in subroutines VZ1 and VZ2. The former is called by VZ2 to compute z_{11} and z_{22} while z_{12} is computed within VZ2 by the following formula for $y_2 > y_1$:

$$z_{12} = -jk_0 t\eta_0 \sum_{m=0}^{\infty} \left\{ \frac{\epsilon_{0m}}{a}\cos(m\pi x_1/a)\cos(m\pi x_2/a)\, j_0^2\left(\frac{m\pi d}{2a}\right)\right.$$

$$\cdot \left. \frac{\cos[p_m(b-y_2)]\cos(p_m y_1)}{p_m \sin(p_m b)} \right\} .$$

For $y_1 = y_2$, this series is accelerated by writing it as

$$z_{12} = -jk_0 t\eta_0 \left\{ \frac{\cos(ky_1)\cos[k(b-y_1)]}{ka\sin(kb)} \right.$$

$$+ \sum_{m=1}^{\infty} \frac{2}{a} \cos(m\pi x_1/a)\cos(m\pi x_2/a) j_0^2 \left(\frac{m\pi d}{2a} \right)$$

$$\cdot \left[\frac{\cos(p_m y_1)\cos[p_m(b-y_1)]}{p_m \sin(p_m b)} + \frac{a\tau}{m\pi} \right] \Bigg\}$$

$$+ \frac{jk_0 t\eta_0 \tau}{\pi^3} \left(\frac{a}{d} \right)^2 \left\{ F\left(\frac{\pi(x_1+x_2)}{a} \right) + F\left(\frac{\pi(x_1-x_2)}{a} \right) \right.$$

$$\left. - \frac{1}{2} \left[F\left(\frac{\pi(x_1+x_2+d)}{a} \right) + F\left(\frac{\pi(x_1+x_2-d)}{a} \right) + F\left(\frac{\pi(x_1-x_2+d)}{a} \right) + F\left(\frac{\pi(x_1-x_2-d)}{a} \right) \right] \right\}$$

where $\tau = 1$ for $b > y_1 > 0$ and $\tau = 2$ for $y_1 = 0$ or $y_1 = b$. The driving point impedance, z_{11}, is computed using the accelerated formula for z_{12} with x_2 and y_2 replaced by x_1 and y_1, respectively. Similarly, z_{22} is computed with x_1 and y_1 replaced by x_2 and y_2.

The function $F(x)$ is related to Clausen's integral and is given by

$$F(x) = \sum_{m=1}^{\infty} \cos \frac{(mx)}{m^3} .$$

This function is written in terms of $\ln x$ and a rapidly converging series of Chebyshev polynomials. It is evaluated in function VF.

V EFFECTIVE LOSS TANGENT

The "effective " loss tangent is found by first computing the fields within the "cavity" based on k found from the *actual* loss tangent of the substrate. From these fields, computations of the electric stored energy, the radiated power, and the power loss in the dielectric and copper are made. From these quantities, the antenna "Q" is computed from

$$Q = \frac{4\pi f W_E}{P_{rad} + P_d + P_{Cu}} .$$

An "effective" loss tangent, δ_{eff}, is defined as

$$\delta_{eff} = \frac{1}{Q} .$$

This loss tangent is then used to compute an improved k and the whole process is repeated to find new (and more accurate) predictions of the stored energy and losses. A new δ_{eff} is found, and so on. The program as supplied computes a twice iterated δ_{eff}. However, for thin substrates, the procedure converges after a single iteration and the first δ_{eff} computed is adequate. A simple modification of the program will eliminate the second iteration.

CHAPTER 2: PROGRAM LISTING

The FORTRAN program listed in this chapter was implemented on the CYBER 175 computer located at the University of Illinois, Urbana, IL. The program uses CDC's "extended FORTRAN" and the Graphics Compatibility System (GCS) produced by the United States Military Academy. Names of subroutines provided by GCS all begin with the letter "U." These GCS routines are used in certain input/output subroutines including those that plot results. Such routines have been listed below in a section entitled "INPUT/OUTPUT AND PLOTTING." It is this section of the program which is rather strongly installation dependent and would probably require user modification.

The other major sections of the program listed below are the "MAIN PROGRAM" and the "NUMERICAL" sections. The former controls the flow of execution of the program while the latter computes the impedance, pattern, *etc.* Both these sections are fairly transportable, particularly the NUMERICAL section. Only a few non-ANSI FORTRAN statements and routines are used in these sections and these can be easily eliminated or modified.

The overall simplified flow-chart of the program is shown in fig. 2. Other details of specific subroutines can be obtained by referring to their respective documentation in comment cards.

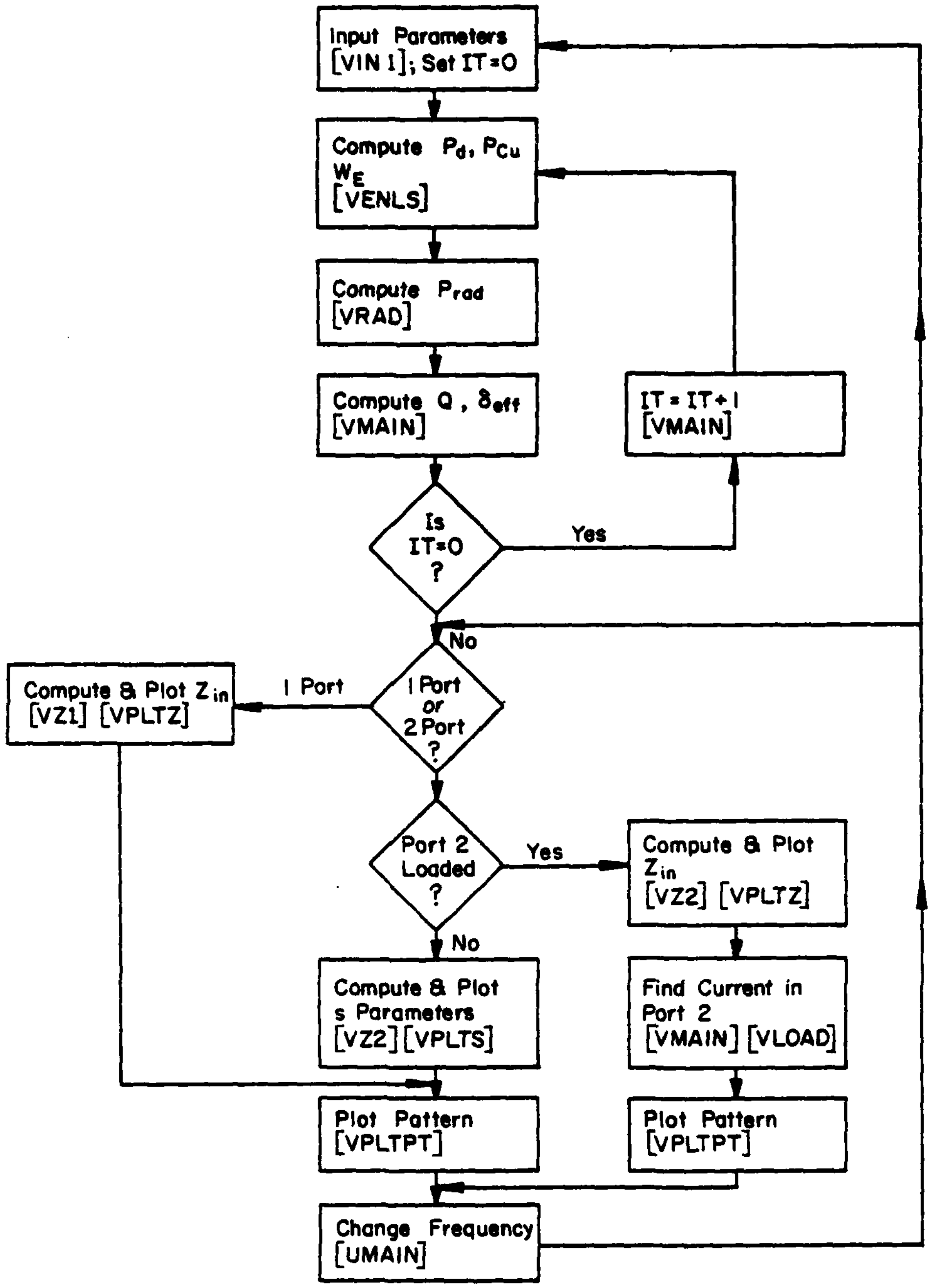


Figure 2. Simplified Flow Chart for the Program

MAIN PROGRAM

```
      PROGRAM VMAIN(INPUT,OUTPUT,TAPE1=OUTPUT,TAPE2=INPUT,RESULT,        N/S
     1              TAPE3=RESULT)
C
C     ***********************************************************************
C     **                                                                   **
C     ** This is the main program of a group of routines that computes     **
C     **  (1)  Input impedance of a                                        **
C     **         (a)  Single port rectangular microstrip antenna;          **
C     **         (b)  Two port rectangular microstrip antenna with one of its **
C     **              ports loaded by a specified impedance (in subroutine **
C     **              "VLOAD");                                            **
C     **  (2)  The "s" parameters of a two port microstrip antenna;        **
C     **  (3)  The radiation pattern of a                                  **
C     **         (a)  Single port rectangular microstrip antenna;          **
C     **         (b)  Two port rectangular microstrip antenna with one of its **
C     **              ports loaded by a specified impedance.               **
C     **                                                                   **
C     ***********************************************************************
C     *                                                                     *
C     *   REFERENCES:  The method used is described in the following        *
C     *   publications:                                                     *
C     *                                                                     *
C     *    [1] Y. T. Lo, D. Solomon, W. F. Richards, "Theory and Experiment on *
C     *        Microstrip Antennas,"  IEEE TRANS. ANTENNAS PROPAGAT. Vol.   *
C     *        AP-27, pp. 137-145, MAR 79.                                  *
C     *                                                                     *
C     *    [2] Y. T. Lo, W. F. Richards, D. D. Harrison, "An Improved Theory *
C     *        for Microstrip Antennas and Applications,"  RADC-TR INTERIM  *
C     *        REPORT (PART I), DEC 78.                                     *
C     *                                                                     *
C     *    [3] W. F. Richards, Y. T. Lo, D. D. Harrison,  "Improved Theory  *
C     *        for Microstrip Antennas,"  IEE ELECTRONICS LETTERS, Vol. 15, *
C     *        pp. 42-44, JAN 79.                                           *
C     *                                                                     *
C     *   LIMITATIONS:                                                      *
C     *   The current version does not include an estimate of surface  wave *
C     *   power as this computation is currently under critical evaluation. *
C     *   This version also requires the specification of the so called    *
C     *   "effective feed width."  This parameter arises from an attempt to *
C     *   idealize the fields in the vicinity of a coaxial or microstrip feed *
C     *   so that the source can be considered as a uniform current         *
C     *   ribbon of width D (the effective width) flowing from the patch to *
C     *   the ground plane.  Since the observed shift of impedance loci into *
C     *   inductive half of the Smith Chart depends rather strongly on the  *
C     *   field distribution in the vicinity of the feed, this idealization *
C     *   needs some refinements and a more rigorous treatment of this      *
C     *   problem is under way.  For the present, the user should try some  *
C     *   different values of D until he finds one which fits measured results *
C     *   most closely.  The representation of the fields for frequencies far *
C     *   away from resonance, say near the mean of two widely spaced adjacent *
C     *   resonant frequencies, is currently not sufficiently accurate for all *
C     *   applications.  We will do further research to develop better compu- *
C     *   tations in this regime.                                           *
C     *                                                                     *
C     *   IMPLEMENTATION REQUIREMENTS:  Except for the input/output which   *
C     *   relies heavily upon the graphics capabilities of the GCS system   *
C     *   developed by the United States Military Academy, the program is  *
C     *   written in ANSI FORTRAN and should be relatively transportable.   *
C     *   All GCS subroutine names begin with a "U" in this program.        *
C     *   Some of the input/output utilizes extended features of CDC's FORTRAN *
C     *   as implemented on the University of Illinoi's CYBER 175 (NOS V. 4.7) *
C     *   and will have to be modified for use on other systems.            *
C     *   Non-ANSI FORTRAN statements are flagged as N/S.                   *
C     *                                                                     *
C     *   USER INSTRUCTIONS:  The parameter descriptions and options are    *
C     *   explaned through the use of examples provided with this listing.  *
C     *                                                                     *
C     ***********************************************************************
C
```

```
      REAL LOSS, K0, LOSSO
      INTEGER P, ANS, PO
      COMPLEX Z, Z11, Z12, Z22, ZL, ZIN, I2
      COMMON /DELTA/ DELTA
      COMMON /OPT/ ANS
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PDO2A, PXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      COMMON /I2/ AO,BO,TO,DO,DIELO,LOSSO,SIGMO,PO,XPO,YPO,XPPO,YPPO,
     *            LO,FOO,BANDO,DELTAO
      DATA AO/0./,BO/0./,TO/0./,DO/0./,DIELO/1./,LOSSO/0./,SIGMO/580./,
     *     PO/1/,XPO/0./,YPO/0./,XPPO/0./,YPPO/0./,LO/"N"/,FOO/0./,
     *     BANDO/0./,DELTAO/0.0/,C/30000./,PI/3.1415926535898/,
     *     TWOPI/6.2831853071796/,ETAO/377./
      CALL USTART
    1 CALL VIN1
      IT = 0
      DELTA = LOSS
C
C     Find the nearest resonant frequency to the specified center frequency
C
      CALL VSEARC (M, N)
      K0 = SQRT(((M*PI/A)**2 + (N*PI/B)**2)/DIEL)
      PDO2A = PI * D / (2 * A)
      PXPOA = PI * XP / A
      BOA = B / A
C
C     Compute "closed form" sum of asymptotic expression of the summand
C     for the driving point impedance series
C
      S1 = VS(XP, XP)
      IF (P .LT. 2) GO TO 2
      S2 = VS(XPP, XPP)
      S3 = VS(XP, XPP)
C
C     Compute stored electric energy, WWE, copper loss, PCU, and dielectric
C     loss, PD, for "effective loss tangent", DELTA.  (Dielectric loss is
C     always computed using the actual loss tangent, LOSS).
C
    2 CALL VENLS (DELTA, WWE, PCU, PD)
C
C     Compute radiated power, PRAD, for effective loss tangent, DELTA
C
      CALL VRAD (DELTA, PRAD)
      POWER = PRAD + PCU + PD
      Q = 2 * WWE / POWER
      DELTA = 1/Q
      IT = IT + 1
C
C     Iterate the calculation twice to ensure proper value of DELTA
C     is obtained.
C
      IF (IT .LT. 2) GO TO 2
C
C     Compute the pattern along the zenith direction to determine
C     antenna gain.
C
      CALL VPAT (0., 0., Z11, Z22, DELTA, (1., 0.), XP, YP)
      E = Z11*CONJG(Z11)+Z22*CONJG(Z22)
      GAIN = 10.*ALOG(2*TWOPI*E/(ETA0*PRAD))
     1       /ALOG(10.)
      F = F0 - (NFREQ/2)*DELTAF
      NO2 = NFREQ/2 + 1
      WRITE (1,7)
      READ (2,8) ANS
      CALL EOF(2)                                                   N/S
      IF (ANS .EQ. 0) ANS = 3
      DO 3 K = 1, NFREQ
        K0 = TWOPI * F / C
```

```
      GO TO (10, 20), P
C
C     Find the driving point impedance of the one port
C
 10   CALL VZ1 (Z, DELTA, XP, YP, S1)
C
C     Input data to the plotting program, VPLTZ
C
      CALL VPLTZ (Z, F, 0)
      GO TO 30
C
C     Compute the "z" parameters of the two port
C
 20   CALL VZ2 (Z11, Z12, Z22, DELTA, S1, S2, S3)
      IF (L .EQ. "N") GO TO 202
C
C       Compute impedance of load on port two of the microstrip
C
        CALL VLOAD (F, ZL)
C
C       Compute the input impedance as seen at port one of the loaded
C       microstrip antenna.
C
        ZIN = Z11 - Z12**2 / (Z22 + ZL)
        CALL VPLTZ (ZIN, F, 0)
C
C       Compute the current flowing through the load at port two.
C
        I2 = -Z12 / (Z22 + ZL)
C
C       Depending on the options chosen, compute the pattern of the antenna.
C
        IF (ANS .EQ. 1 .OR. (ANS .EQ. 2 .AND. K .EQ. NO2))
     1      CALL VPLTPT (I2, F)
        GO TO 3
C
C       Input the two port parameters to the "s" parameter plotting
C       program for the case of a non-loaded two port antenna.
C
202     CALL VPLTS (F, Z11, Z12, Z22, 0)
 30   IF (ANS .EQ. 1 .OR. (ANS .EQ. 2 .AND. K .EQ. NO2))
     1      CALL VPLTPT (I2, F)
   3 F = F + DELTAF
     IF (P .EQ. 1) GO TO 5
     IF (L .NE. "N") GO TO 5
C
C    Plot "s" parameters
C
     CALL VPLTS (FO, Z11, Z12, Z22, 1)
     GO TO 6
C
C    Plot the input impedance to the microstrip.
C
   5 CALL VPLTZ (Z, FO, 1)
   6 WRITE (1,9)
     READ (2,11) ANS
     CALL EOF(2)                                                  N/S
     IF (ANS .EQ. 0) ANS = "Y"
     IF (ANS .EQ. "Y") GO TO 1
     STOP
   7 FORMAT ("Choose an option:",/,
    1        "  (1) Plot patterns at",
    2" all frequencies.",/,
    3        "  (2) Plot pattern only",
    4" at center frequency.",/,
    5        "  (3) Plot no patterns",/,
    6"Type option (1, 2, or 3): ",)
   8 FORMAT(I1)
   9 FORMAT ("Continue (type Y or N) ",)
```

```
11 FORMAT (A1)
   END
```

```
      SUBROUTINE VDOUBL (F, M, A, B, C, D, INT)
C
C     ***********************************************************************
C     *                                                                     *
C     *  PURPOSE:  This subroutine performs the integral from 0 to A of the *
C     *            integral from 0 to B of the externally declared function *
C     *            F(X,Y).                                                  *
C     *                                                                     *
C     *  PARAMETERS:  The parameters are as stated above and M is the log base *
C     *            two plus one of the number of point Gaussian quadrature  *
C     *            formula used in the mechanical quadrature.  INT is the   *
C     *            integral.                                                *
C     *                                                                     *
C     ***********************************************************************
C
      REAL INT, W(31), S(31)
      DATA W / 1.00000000000000, .65214515486255, .34785484513745,
     *          .36268378337836, .31370664587789, .22238103445337,
     *          .10122853629038, .18945061045507, .18260341504492,
     *          .16915651939500, .14959598881658, .12462897125553,
     *          .09515851168249, .06225352393865, .02715245941175,
     *          .09654008851473, .09563872007927, .09384439908080,
     *          .09117387869576, .08765209300440, .08331192422695,
     *          .07819389578707, .07234579410885, .06582222277636,
     *          .05868409347854, .05099805926238, .04283589802223,
     *          .03427386291302, .02539206530926, .01627439473091,
     *          .00701861000947/
      DATA S /  .57735026918963, .33998104358486,
     *          .86113631159405, .18343464249565, .52553240991633,
     *          .79666647741363, .96028985649754, .09501250983764,
     *          .28160355077926, .45801677765723, .61787624440264,
     *          .75540440835500, .86563120238783, .94457502307323,
     *          .98940093499165, .04830766568774, .14447196158280,
     *          .23928736225214, .33186860228213, .42135127613064,
     *          .50689990893223, .58771575724076, .66304426693022,
     *          .73218211874029, .79448379596794, .84936761373257,
     *          .89632115576605, .93490607593774, .96476225558751,
     *          .98561151154527, .99726386184948/
      L1 = 2**(M-1)
      N1 = 2*L1 - 1
      F1 = (B-A)/2
      F2 = (D-C)/2
      F3 = (B+A)/2
      F4 = (D+C)/2
      INT = 0.
      DO 2 J = L1, N1
         SUM = 0.
         DO 1 K = L1, N1
            T1 = F1 * S(K)
            T2 = F2 * S(J)
            T3 = T1 + F3
            T4 = T2 + F4
            T5 = F3 - T1
            T6 = F4 - T2
    1    SUM = SUM+W(K)*(F(T3,T4)+F(T3,T6)+F(T5,T4)+F(T5,T6))
    2 INT = INT + W(J) * SUM
      INT = INT * F1 * F2
      RETURN
      END
```

```
      SUBROUTINE VENLS(DELTA,ESE,DL,CL)
C
C     ************************************************************************
C     *                                                                      *
C     * PURPOSE: This subroutine computes the electric stored energy and the *
C     *          copper and dielectric losses at resonance.                  *
C     *                                                                      *
C     * PARAMETERS: DELTA is the effective loss tangent.  ESE is the computed *
C     *          electric stored energy (at the nearest resonance to F0 as   *
C     *          determined by subroutine VSEARC).  DL is the dielectric loss *
C     *          computed using the actual loss tangent.  CL is the copper loss*
C     *          computed as a proportion of the dielectric loss.            *
C     *                                                                      *
C     ************************************************************************
C
      REAL MPI,MPIOA,MPIOA2,LT,J0,N,K0
      COMPLEX K,SPB,P,PYP,PSPB,PBMYP,CPYP,CPBMYP
      COMMON /I1/ A, B, T, D, EPS, LT, SIGM,IP, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PDO2A, TPXPOA, BOA, BAND, PI,
     *            ETA, KK, GAIN, DELTAF
      K = CSQRT(CMPLX(EPS,-DELTA*EPS)) * K0
      SD = SQRT(2/(1000*K0*ETA*SIGM))
      BMYP=B-YP
      CPYP=CCOS(K*YP)
      CPBMYP=CCOS(K*BMYP)
      SPB=CSIN(K*B)
      F1=YP* (CABS(CPBMYP))**2
      F2=BMYP*(CABS(CPYP))**2
      ESE=(F1*N(K*YP)+F2*N(K*BMYP))/(CABS(K*SPB))**2
      M1=0
100   CONTINUE
      M1=M1+1
      MPI=M1*3.141592654
      MPIOA=MPI/A
      MPIOA2=MPIOA**2
      P=CSQRT(K*K-MPIOA2)
      PSPB=P*CSIN(P*B)
      PYP=P*YP
      PBMYP=P*BMYP
      CPYP=CCOS(PYP)
      CPBMYP=CCOS(PBMYP)
      CF=(J0(M1*PDO2A)*COS(MPI*XP/A))**2
      F=2./(CABS(PSPB))**2
      F1=YP*(CABS(CPBMYP))**2
      F2=BMYP*(CABS(CPYP))**2
      T3=(F1*N(PYP)+F2*N(PBMYP))*F
      IF (MOD(M1,2) .EQ. 0) GO TO 150
      SUBTOT = CF*T3
      GO TO 100
  150 SUBTOT = SUBTOT + CF*T3
      ESE=ESE+SUBTOT
      IF (SUBTOT/ESE .LT. 0.0001) GO TO 200
      GO TO 100
200   ESE=ESE*EPS*T*K0**3*ETA/(2*A)
      DL=2*LT*ESE
      CL=SD*DL/(T*LT)
      RETURN
      END
```

```
      FUNCTION VF(Z)
C
C     ************************************************************************
C     *                                                                      *
C     *  PURPOSE:  This routine computes a sum related                       *
C     *            to the integral of Clausen's integral:                    *
C     *                                                                      *
C     *            Sum from k = 1 to infinity of cos(kZ)/k**3.               *
C     *                                                                      *
C     *  METHOD:   A Tchebyshev series was derived from                      *
C     *            expansions given in Abromowitz & Stegun                   *
C     *            and is summed by Clenshaw's algorithm.                    *
C     *                                                                      *
C     ************************************************************************
C
      REAL C1(9), C2(9), LN2O2
      DATA C1/   .06905464409766968,
     1           .00052071642034163,
     2           .00000505847024742,
     3           .00000006775156996,
     4           .00000000107462004,
     5           .00000000001896987,
     6           .00000000000036087,
     7           .00000000000000726,
     8           .00000000000000015/
       DATA C2 /.20855205969900512,
     1          .00297532164412 84,
     2          .00004069998173 26,
     3          .00000069267567 91,
     4          .00000001327258 92,
     5          .00000000027439 22,
     6          .00000000000598 18,
     7          .00000000000013 56,
     8          .00000000000000 32/
      TWOPI = 6.283185307179586
      PIBY3 = 1.047197551196598
      ZETA3 = 1.202056903159594
      LN2O2 = .3465735902799726
      X = ABS(Z)
      IX = X / TWOPI
      IF (X .LT. 0.) IX = IX - 1
      Y = X - TWOPI * IX
      IF (Y .GT. 3.141592653589793) Y = TWOPI - Y
      KODE = 1
      IF (Y .GE. 2.094395102393196) KODE = 2
      IF (KODE .EQ. 2) Y = 3.141592653589793 - Y
      T = Y / PIBY3
      IF (KODE .EQ. 1) T = T / 2.
      T2TSM1 = 2. * (2. * T**2  -  1.)
      G1 = 0.
      G2 = 0.
      DO 4 L = 1, 9
        FACTOR = T2TSM1
        IF (L .EQ. 9) FACTOR = .5 * FACTOR
        G0 = FACTOR * G1  -  G2
        GO TO (1,2), KODE
    1   C = C1(10-L)
        GO TO 3
    2   C = C2(10-L)
    3   G0 = G0 + C
        G2 = G1
        G1 = G0
    4 CONTINUE
      G0 = G0 * (Y / TWOPI)**2
      GO TO (5,6), KODE
    5 VF = ZETA3
      IF (Y .NE. 0.) VF = VF + Y**2 * (0.5 * ALOG(Y) - 0.75 - 2.*G0)
      GO TO 7
    6 VF = -0.75 * ZETA3 + Y**2 * (LN2O2 - 2. * G0)
    7 RETURN
      END
```

```
      SUBROUTINE VLOAD(F, ZL)
C
C     ***********************************************************************
C     *                                                                     *
C     *  PURPOSE:  This is an example of the format of user supplied subroutine*
C     *            VLOAD.  The purpose of the subroutine is to return a load  *
C     *            impedance, stored in ZL, at a frequency, F.  Many of the   *
C     *            electrical and geometrical parameters of the antenna are   *
C     *            available to this routine through common block /I1/.       *
C     *            Also, the parameter "K" is availble through this common    *
C     *            block.  This parameter is a "DO" index for the loop that   *
C     *            increments frequency in the main program.  Thus, as was done*
C     *            in this example, and "IF" statement testing to see if K is *
C     *            one or not can be included so that data can be input by this*
C     *            program.  Another common block, /LDID/ contains a string   *
C     *            which allows one to give a verbal description of the type of*
C     *            load defined in the subroutine.  The description must be 40 *
C     *            characters or less in the CYBER system.                    *
C     *                                                                     *
C     ***********************************************************************
C
      COMPLEX ZL
      INTEGER STRING(4)
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PDO2A, PXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      COMMON /LDID/ STRING
      IF (K .GT. 1) GO TO 1
      PRINT *, "INPUT CAPACITANCE IN PICOFARADS:  C = ",                N/S
      READ *, C
      ENCODE (40, 2, STRING) C                                          N/S
      C = C * 1.E-6
    1 ZL = CMPLX(0.,-1./(F*TWOPI*C))
    2 FORMAT ("CAPACITIVE LOAD: C = ",E8.2,"           ")
      RETURN
      END
```

```
C
C     ***********************************************************************
C     *                                                                     *
C     *  PURPOSE:  This routine returns a load impedance of zero, (the      *
C     *            impedance of a short).  It is loaded as the defualt VLOAD *
C     *            subroutine.                                              *
C     *                                                                     *
C     ***********************************************************************
C
      SUBROUTINE VLOAD(F, ZL)
      INTEGER STRING(4)
      COMPLEX ZL
      COMMON /LDID/ STRING
      DATA STRING /"short circuit                  "/
      ZL = (0.,0.)
      RETURN
      END
```

```
C     ***********************************************************************
C     *                                                                     *
C     * PURPOSE: This group of functions compute certain quantities used in the*
C     *          evaluation of electric stored energy computed in subroutine  *
C     *          VENLS.                                                      *
C     ***********************************************************************
C
      REAL FUNCTION M (Z)
      COMPLEX Z
      REAL J0, I0
      M = (I0(2*AIMAG(Z)) - J0(2*REAL(Z)))/2
      RETURN
      END
      REAL FUNCTION N (Z)
      COMPLEX Z
      REAL J0, I0
      N = (J0(2*REAL(Z)) + I0(2*AIMAG(Z)))/2
      RETURN
      END
      REAL FUNCTION I0 (X)
      T = EXP(X)
      I0 = 1.
      IF (X .NE. 0.) I0 = (T - 1/T) / (2*X)
      RETURN
      END
```

```
      SUBROUTINE VPAT (THETA, PHI, ETHETA, EPHI, DELTA, I, X, Y)
C
C     ***************************************************************************
C     *                                                                         *
C     * PURPOSE:  To evaluate the electric far field at direction              *
C     *           (THETA,PHI)                                                   *
C     *                                                                         *
C     * PARAMETERS:  ETHETA and EPHI are the THETA and PHI                      *
C     *           components of electric field.  DELTA is the                   *
C     *           loss tangent used in the computation.                        *
C     *                                                                         *
C     ***************************************************************************
C
      COMPLEX ETHETA, EPHI, FX, FY, PM, KSQ, PMB, PMY, CPY, CPBMY,I,XF,
     *        F, PMBSPB, EKYSS, EKBSS, XT, YT, XTERM, YTERM, D2, FACTOR
      REAL K0, MPI, KASC, KBSS, KYSS, J0
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PDO2A, TPXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      PXOA = PI * X / A
      FX = (0.,0.)
      FY = (0.,0.)
      M = 0
      CT = COS(THETA)
      ST = SIN(THETA)
      CP = COS(PHI)
      SP = SIN(PHI)
      KYSS = K0 * Y * SP * ST
      KBSS = K0 * B * SP * ST
      KASC = K0 * A * CP * ST
      KSQ = DIEL * K0**2 * CMPLX(1., -DELTA)
    1 MPI = M * PI
      PM = CSQRT(KSQ - (MPI/A)**2)
      PMY  = PM * Y
      PMB   = PM * B
      CPY   = CCOS(PMY)
      CPBMY = CCOS(PMB-PMY)
      PMBSPB = CSIN(PMB) * PMB
      EKYSS = CEXP(CMPLX(0.,KYSS))
      EKBSS = CEXP(CMPLX(0.,KBSS))
      D1 = MPI**2 - KASC**2
      D2 = PMB**2 - KBSS**2
      XF = CPY * EKBSS - CPBMY
      F = CEXP(CMPLX(0.,KASC))
      IF (M .NE. 2*(M/2)) F = -F
      F = F - 1.
      IF (ABS(D1) .GT. 1.E-5) GO TO 2
C
C   >>>------>  Find limiting value of expression when D1 ----> 0.
C
      XT = XF
      IF (M .GT. 0) XT = XT / 2.
      GO TO 3
    2 XT = XF * F * CMPLX(0.,KASC) / D1
    3 YT = -BOA * F * (PMBSPB * EKYSS + CMPLX(0.,KBSS)*XF) / D2
      FACTOR = COS(M * PXOA) * J0(M * PDO2A) / (PMBSPB)
      IF (M .GT. 0) FACTOR = FACTOR * 2.
      M = M + 1
      IF (MOD(M,2) .EQ. 0) GO TO 30
      XTERM = FACTOR * XT
      YTERM = FACTOR * YT
      GO TO 1
   30 XTERM = XTERM + FACTOR * XT
      YTERM = YTERM + FACTOR * YT
      FX = FX + XTERM
      FY = FY + YTERM
      IF (SQRT(CABS(XTERM)**2 + CABS(YTERM)**2) .LT. 0.0001 *
     *    SQRT(CABS(FX)**2 + CABS(FY)**2)) GO TO 4
      GO TO 1
```

```
4 FACTOR = KO**2 * T * ETAO * B / TWOPI
  ETHETA = (-FX*SP + FY*CP) * FACTOR * I
  EPHI = -(FX*CP + FY*SP) * CT * FACTOR * I
  RETURN
  END

  REAL FUNCTION JO(X)
  JO = 1.
  IF (X .NE. 0.) JO = SIN(X) / X
  RETURN
  END
```

```
      FUNCTION VPPAT (THETA, PHI)
C
C     ******************************************************************
C     *                                                                *
C     *  PURPOSE:  THIS SUBROUTINE COMPUTES THE POWER PATTERN (TIMES THE SIN OF *
C     *            OF THE POLAR ELEVATION ANGLE, THETA) FROM THE COMPLEX PATTERN *
C     *            COMPUTED IN SUBROUTINE VPAT.                        *
C     *                                                                *
C     *  PARAMETERS:  (THETA, PHI) IS THE DIRECTION OF OBSERVATION IN SPHERICAL *
C     *            COORDINATES.                                        *
C     *                                                                *
C     ******************************************************************
C
      COMPLEX ETHETA, EPHI
      COMMON /DELTA/ DELTA
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PDO2A, TPXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      CALL VPAT (THETA, PHI, ETHETA, EPHI, DELTA, (1.,0.), XP, YP)
      VPPAT = SIN(THETA) * (ETHETA * CONJG(ETHETA) + EPHI * CONJG(EPHI))
      RETURN
      END
```

```
      SUBROUTINE VRAD (DELTA, PRAD)
C
C     **************************************************************************
C     *                                                                        *
C     * PURPOSE: To evaluate the power radiated by the microstrip antenna      *
C     *                                                                        *
C     * PARAMETERS: DELTA is the effective loss tangent, and PRAD is the       *
C     *        radiated power computed using numerical quadrature.             *
C     *                                                                        *
C     **************************************************************************
C
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PD02A, TPXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      EXTERNAL VPPAT
      CALL VDOUBL (VPPAT, 3, 0., PI/2., 0., TWOPI, PRAD)
      PRAD = PRAD / ETA0
      RETURN
      END
```

```
      FUNCTION VS (X1, X2)
C
C     ******************************************************************
C     *                                                                *
C     *  PURPOSE:  THIS FUNCTION EVALUATES THE CONTRIBUTION DUE TO THE FIRST  *
C     *            TERM IN THE ASYMPTOTIC SERIES OF THE SUMMAND IN THE Z-PARAM *
C     *            EXPRESSIONS.  (THIS IS USED TO APPLY KUMMER'S TRANSFORMATION*
C     *            TO ACCELERATE THE CONVERGENCE OF THE SERIES).        *
C     *                                                                *
C     *  PARAMETERS:  X1 AND X2 ARE THE ABSCISSA OF THE LOCATIONS OF PORTS 1   *
C     *            AND 2, RESPECTIVELY.                                *
C     *                                                                *
C     ******************************************************************
C
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PD02A, TPXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      F1 = PI * (X1 + X2) / A
      F2 = PI * (X1 - X2) / A
      F3 = PI * (X1 + X2 + D) / A
      F4 = PI * (X1 + X2 - D) / A
      F5 = PI * (X1 - X2 + D) / A
      F6 = PI * (X1 - X2 - D) / A
      VS = VF(F3) + VF(F4) + VF(F5) + VF(F6)
      VS = VF(F1) + VF(F2) - 0.5 * VS
      VS = - (A/D)**2 * (1/PI)**3  *  VS
      RETURN
      END
```

```
      SUBROUTINE VSEARC (MO, NO)
C
C     ************************************************************************
C     *                                                                      *
C     * PURPOSE: This subroutine searches for the combination of mode indices, *
C     *          (MO,NO) which yields the resonant wave number closest two the *
C     *          wave number of free space at the chosen center frequency     *
C     *          times the permitivity of the dielectric.                     *
C     *                                                                      *
C     ************************************************************************
C
      REAL MIN, KG, KMN
      INTEGER V
      COMMON /I1/ A, B,TT, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            FO, NFREQ, KO, TWOPI, PDO2A, TPXPOA, BOA, BAND, PI,
     *            ETAO, K, GAIN, DELTAF
      DATA C/30000./
      KG = TWOPI * FO * SQRT(DIEL) / C
      M = KG * A / PI
      N = 0
      MIN = (M+1) * PI / A - KG
      MO = M + 1
      NO = 0
      V = 1
    1 IF (V .EQ. 1) GO TO 2
      M = M - 1
      GO TO 3
    2 N = N + 1
    3 KMN = SQRT((M*PI/A)**2 + (N*PI/B)**2)
      IF (KMN .LT. KG) GO TO 4
      V = 0
      GO TO 5
    4 V = 1
    5 T = ABS(KMN - KG)
      IF (T .GE. MIN) GO TO 6
      MIN = T
      MO = M
      NO = N
    6 IF (M .NE. 0) GO TO 1
      IF (V .EQ. 1) GO TO 7
      N = N - 1
      GO TO 8
    7 N = N + 1
    8 T = ABS(N*PI/B - KG)
      IF (T .GE. MIN) RETURN
      MO = 0
      NO = N
      RETURN
      END
```

```
      SUBROUTINE VZ1 (Z, DELTA, X, Y, S)
C
C     ****************************************************************
C     *                                                              *
C     * PURPOSE: This subroutine computes the driving point impedance of a *
C     *          rectangular microstrip antenna feed at point (X,Y).  *
C     *                                                              *
C     * PARAMETERS: Z is the complex driving point impedance.   DELTA is the *
C     *          effective loss tangent.  (X,Y) is the coordinate of the feed. *
C     *          S is the "closed form" sum of the asymptotic form of the *
C     *          summand for Z.  (It is used to accelerate the convergence *
C     *          the series.                                          *
C     *                                                              *
C     ****************************************************************
C
      COMPLEX Z, TERM, K, KSQ, PM, PMB, PY, PBMY, SUBTOT
      REAL MPI, KO, LOSS, JO
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            FO, NFREQ, KO, TWOPI, PDO2A, PXPOA, BOA, BAND, PI,
     *            ETAO, KK, GAIN, DELTAF
      TAU = 1.0
      IF (Y .EQ. 0.) TAU = 2.
      KSQ = DIEL * KO**2 * CMPLX(1.,-DELTA)
      K = CSQRT(KSQ)
      Z = A * S + CCOS(K*Y) * CCOS(K*(B-Y)) / (K*CSIN(K*B))
      M = 0
      SUBTOT = (0., 0.)
      PXOA = PI * X / A
    1 M = M + 1
      MPI = M * PI
      PM = CSQRT(KSQ - (MPI/A)**2)
      PMB = PM * B
      PY = PM * Y
      PBMY = PMB - PY
      TERM = (2*CCOS(PY)*CCOS(PBMY)/(PM*CSIN(PMB)) + TAU*A/MPI) *
     *       (COS(M*PXOA) * JO(M*PDO2A))**2
      SUBTOT = SUBTOT + TERM
      IF (3*(M/3) .NE. M) GO TO 1
      Z = Z + SUBTOT
      IF (CABS(SUBTOT) .LT. 0.001 * CABS(Z)) GO TO 2
      SUBTOT = (0.,0.)
      GO TO 1
    2 Z = -Z * CMPLX(0.,1.) * KO * T * ETAO / A
      RETURN
      END
```

```
      SUBROUTINE VZ2 (Z11, Z12, Z22, DELTA, S1, S2, S3)
C
C     ********************************************************************
C     *                                                                  *
C     * PURPOSE: This subroutine computes the open circuit parameters of the *
C     *          two port with port one at (XP,YP) and port two at (XPP,YPP) *
C     *          (where these parameters are in common block I1).        *
C     *                                                                  *
C     * PARAMETERS: Z11, Z12, and Z22 are the computed open circuit parameters *
C     *          DELTA is the effective loss tangent.  S1, S2, and S3 are the *
C     *          "closed form" sums of the asymptotic form of the summands *
C     *          corresponding to Z11, Z12, and Z22 summations, respectively. *
C     *                                                                  *
C     ********************************************************************
C
      COMPLEX Z11, Z12, Z22, TERM, K, KSQ, PM, PMB, PYP, PBMYPP,SUBTOT
      REAL MPI, KO, LOSS, JO
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P,XXP,YYP,XXPP,YYPP, L,
     *            FO, NFREQ, KO, TWOPI, PDO2A, PXPOA, BOA, BAND, PI,
     *            ETAO, KK, GAIN, DELTAF
      IF (YYP .LT. YYPP) GO TO 10
      XP = XXPP
      YP = YYPP
      XPP = XXP
      YPP = YYP
      GO TO 20
   10 XP = XXP
      YP = YYP
      XPP = XXPP
      YPP = YYPP
   20 TAU = 1.0
      IF (YP .EQ. 0.) TAU = 2.
      KSQ = DIEL * KO**2 * CMPLX(1.,-DELTA)
      K = CSQRT(KSQ)
      KODE = 1
      Z12 = CCOS(K*(B-YPP)) * CCOS(K*YP) / (K*CSIN(K*B))
      IF (ABS(YP - YPP) .LT. 0.001) KODE = 2
      IF (KODE .EQ. 2) Z12 = Z12 + S3 * A
      M = 0
      SUBTOT = (0.,0.)
      PXPOA = PI * XP / A
      PXPPOA = PI * XPP / A
    1 M = M + 1
      MPI = M * PI
      PM = CSQRT(KSQ - (MPI/A)**2)
      PMB = PM * B
      PYP = PM * YP
      PBMYPP = PM * (B - YPP)
      TERM = 2*CCOS(PBMYPP) * CCOS(PYP) / (PM*CSIN(PMB))
      IF (KODE .EQ. 2) TERM = TERM + TAU*A/MPI
      TERM = TERM * COS(M*PXPOA) * COS(M*PXPPOA) * JO(M*PDO2A)**2
      SUBTOT = SUBTOT + TERM
      IF (3*(M/3) .NE. M) GO TO 1
      Z12 = Z12 + SUBTOT
      IF (CABS(SUBTOT) .LT. 0.000001 * CABS(Z12)) GO TO 2
      SUBTOT = (0.,0.)
      GO TO 1
    2 Z12 = -Z12 * CMPLX(0.,1.) * KO * T * ETAO / A
      CALL VZ1 (Z11, DELTA,XXP,YYP, S1)
      CALL VZ1 (Z22, DELTA,XXPP,YYPP, S2)
      RETURN
      END
```

```
      SUBROUTINE VZTOS(Z11,Z12,Z22,S11,S12,S22)
C
C     ******************************************************************************
C     *                                                                            *
C     * PURPOSE: This program converts the open circuit parameters to             *
C     *          scattering parameters refered to a 50 ohm system.                 *
C     *                                                                            *
C     * PARAMETERS: The open circuit parameters are Z11, Z12, and Z22 and are      *
C     *          are converted to the scattering parameters S11, S12, and S22.     *
C     *                                                                            *
C     ******************************************************************************
C
      COMPLEX Z11,Z12,Z22,S11,S12,S22
      Z0=50
      S11=((Z11-Z0)*(Z22+Z0)-Z12**2)/((Z11+Z0)*(Z22+Z0)-Z12**2)
      S12=2.*Z0*Z12/((Z11+Z0)*(Z22+Z0)-Z12**2)
      S22=((Z11+Z0)*(Z22-Z0)-Z12**2)/((Z11+Z0)*(Z22+Z0)-Z12**2)
      RETURN
      END
```

INPUT/OUTPUT AND PLOTTING

```
      SUBROUTINE VIN1
C
C     ************************************************************************
C     *                                                                      *
C     *  PURPOSE:  To provide input of antenna parameters.                   *
C     *                                                                      *
C     ************************************************************************
C
      INTEGER P, PO
      REAL LOSS, LOSSO
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            FO, NFREQ, KO, TWOPI, PDO2A, TPXPOA, BOA, BAND, PI,
     *            ETAO, K, GAIN, DELTAF
      COMMON /I2/ AO,BO,TO,DO,DIELO,LOSSO,SIGMO,PO,XPO,YPO,XPPO,YPPO,
     *            LO,FOO,BANDO,DELTAO
      WRITE (1,1)                                                   OPT
    1 FORMAT ("^>^=^*^*^*^*^*^*^$^$^$^$^$^$^*^*^*^*^*^*",/,
    1         "^$^$^$^$^$^$^*^*^*^*^*^*^$^$^$^$^$^$^*^*^*^*^*^*",/,
    1         "^$^$^$^$^$^$^*^*^*^*^*^*^$^$^$^$^$^$^*^*^*^*^*^*",/,
    1         "^$^$^$^$^$^$^*^*^*^*^*^*^$^$^$^$^$^$^*^*^*^*^*^*",/,
    1         "^$^$^$^$^$^$^*^*^*^*^*^*^$^$^$^$^$^$^*^*^*^*^*^*")
C                                                                   OPT
C  >>-----> Erase sequence + non-printing buffer characters         OPT
C           for Tektronix graphics terminals.                       OPT
C                                                                   OPT
      WRITE (1,2)
    2 FORMAT(" .  a  .  b  . t . d .diel.loss.sigm.p.")
    3 FORMAT (F5.0,X,F5.0,X,F3.0,X,F3.0,X,F4.0,X,F4.0,X,F4.0,X,I1)
      READ (2,3) A, B, T, D, DIEL, LOSS, SIGM, P
      IF(EOF(2).EQ.0) LOSS = LOSS/1000.                             OPT N/S
      IF (A .EQ. 0.) A = AO
      IF (B .EQ. 0.) B = BO
      IF (T .EQ. 0.) T = TO
      IF (D .EQ. 0.) D = DO
      IF (DIEL .EQ. 0.) DIEL = DIELO
      IF (LOSS .EQ. 0.) LOSS = LOSSO
      IF (SIGM .EQ. 0.) SIGM = SIGMO
      IF (P .EQ. 0) P = PO
      IF (A * B * T * D * DIEL * LOSS * SIGM .EQ. 0.) GO TO 10
      AO = A
      BO = B
      TO = T
      DO = D
      DIELO = DIEL
      LOSSO = LOSS
      SIGMO = SIGM
      PO = P
      IF (P .GT. 1) GO TO 6
      WRITE (1,4)
    4 FORMAT (" .  x'  .  y'  .")
      READ (2,5) IXP, IYP
    5 FORMAT (A5,X,A5)
      I = EOF(2)                                                    OPT N/S
      GO TO 9
    6 WRITE (1,7)
    7 FORMAT (" .  x'  .  y'  .  x""  .  y""  .L.")
      READ (2,8) IXP, IYP, IXPP, IYPP, L
    8 FORMAT (A5,X,A5,X,A5,X,A5,X,A1)
      I = EOF(2)                                                    OPT N/S
      IF (L .NE. "Y" .AND. L .NE. "N") L = LO
      DECODE (5,12,IXPP) XPP                                        N/S
      DECODE (5,12,IYPP) YPP                                        N/S
      IF (IXPP .EQ. "     ") XPP = XPPO
      IF (IYPP .EQ. "     ") YPP = YPPO
      XPPO = XPP
      YPPO = YPP
      LO = L
    9 DECODE (5,12,IXP) XP                                          N/S
```

```
      DECODE (5,12,IYP) YP                                                N/S
      IF (IXP .EQ. "     ") XP = XPO
      IF (IYP .EQ. "     ") YP = YPO
      XPO = XP
      YPO = YP
      GO TO 13
   10 WRITE (1,11)
   11 FORMAT ("^*^*^*^* INPUT DATA IS BAD / JOB ABORTED")
      STOP
   12 FORMAT (F5.0)
   13 WRITE (1,14)
   14 FORMAT ("  .    ^FO    .^B^A^N^D. @B^/_^F .")
      READ (2,15) FO, BAND, DELTAF
   15 FORMAT (F8.0,X,F4.0,X,F4.0)
      I = EOF(2)
      IF (FO .EQ. 0) FO = FOO
      IF (BAND .EQ. 0.) BAND = BANDO
      IF (DELTAF .EQ. 0) DELTAF = DELTAO
      IF (FO * BAND * DELTAF .EQ. 0) GO TO 10
      BANDO = BAND
      DELTAO = DELTAF
      FOO = FO
      NFREQ = 1
      IF (DELTAF .NE. 0.) NFREQ = 0.5 + BAND*FO/(100*DELTAF)+1
      IF (NFREQ .EQ. 2*(NFREQ/2)) NFREQ = NFREQ + 1
      RETURN
      END
```

```
      SUBROUTINE VPLTPT (I2, F)
C
C     **********************************************************************
C     *                                                                    *
C     * PURPOSE:  This subroutine plots the patterns of a rectangular      *
C     *           microstrip antenna.                                      *
C     *                                                                    *
C     * PARAMETERS:  I2 is the current calculated to flow through port 2   *
C     *              when a load impedance (found in VLOAD) is attached to *
C     *              it.  F is the frequency.                              *
C     *                                                                    *
C     * OPTIONS:  Both polarizations in two planes, X-Z and Y-Z are plotted*
C     *           if the "linear option" is chosen.  If the "CP"           *
C     *           (circular polarization) option is chosen, then the       *
C     *           response of a rotating dipole is simulated for the two   *
C     *           aforementioned planes.  All scales are linear (not dB).  *
C     *           If the "individual normalization" option is chosen, then *
C     *           each pattern is normalized by its own maximum over the   *
C     *           scan.  The relative "cross-pol" cannot be seen with this *
C     *           option.  At the end of each plot, a character must be    *
C     *           input.  The characters that are allowed have the         *
C     *           following meanings:                                      *
C     *                                                                    *
C     *           CHARACTER  STANDS FOR               EFFECT               *
C     *                                                                    *
C     *               S      status        Next plot is same type as       *
C     *                                    previous plot.                  *
C     *                                                                    *
C     *               M      manual        Ask for options for next plot.  *
C     *                                                                    *
C     *               A      automatic     Same as "S" except no further   *
C     *                                    input of options are possible   *
C     *                                    and the plot is automatically   *
C     *                                    copied.                         *
C     *                                                                    *
C     *               R      re-plot       Re-plot last graph.             *
C     *                                                                    *
C     *               T      terminate     Terminate all plotting.         *
C     *                                                                    *
C     **********************************************************************
C
      COMPLEX ET, ET1, EP, EP1, I2
      INTEGER P, ANS, NORM, CP, FREQ(2)
      COMMON /DELTA/ DELTA
      COMMON /OPT/ ANS
      COMMON /JID/ ID
      COMMON /I1/ AZ, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            FO, NFREQ, KO, TWOPI, PDO2A, PXPOA, BOA, BAND, PI,
     *            ETAO, K, GAIN, DELTAF
      DIMENSION EXZX(721), EXZY(721), EYZX(721), EYZY(721), ID(3),
     1          C(8), S(8)
      DATA NORM /0/, INITIAL /0/
      IF (INITIAL .NE. 0) GO TO 400
      IXZ = "X-Z;"
      IYZ = "Y-Z;"
      IO = "O;"
      IDASH = "-;"
      ISLASH = "/;"
      PIBY180 = PI/180.
      PIBY2 = PI/2.
      PIBY8 = PI / 8
      DO 300 J = 1, 8
      ANGLE = (J-1) * PIBY8
      C(J) = COS(ANGLE)
  300 S(J) = SIN(ANGLE)
  400 IF (NORM .NE. 0) GO TO 77
      PRINT *, "^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*"        N/S
      PRINT *, "^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!"        N/S
```

```
      PRINT *, "^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*"          N/S
      PRINT *, "CP OR LINEAR (TYPE C OR L) ",
      READ 75, CP
      IF (CP .EQ. "C") GO TO 76
      FACTOR = PIBY180
      FACT = 1.0
      DENSE = 91
      LIMIT = 181
      PRINT *, "^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*"          N/S
      PRINT *, "INDIVIDUAL NORMALIZATION (Y OR N)  ",                       N/S
      READ 75, IQ
   75 FORMAT (A1)
      GO TO 77
   76 FACTOR = PIBY180/4.
      FACT = 0.25
      DENSE = 361
      LIMIT = 721
   77 DO 3 J = 1, LIMIT
      IF (CP .EQ. "C") IPSI = MOD(J-1,8) + 1
      ANGLE = (DENSE-J) * FACTOR
      CALL VPAT (ANGLE, 0., ET, EP, DELTA, (1.,0.), XP, YP)
      IF (P .EQ. 1) GO TO 1
      CALL VPAT (ANGLE, 0., ET1, EP1, DELTA, I2, XPP, YPP)
      EP = EP + EP1
      ET = ET + ET1
    1 IF (CP .EQ. "C") GO TO 111
      EXZX(J) = CABS(ET)
      EXZY(J) = CABS(EP)
      GO TO 112
  111 EXZX(J) = CABS(EP*C(IPSI)+ET*S(IPSI))
  112 CALL VPAT (ANGLE, PIBY2, ET, EP, DELTA, (1.,0.), XP, YP)
      IF (P .EQ. 1) GO TO 2
      CALL VPAT (ANGLE, PIBY2, ET1, EP1, DELTA, I2, XPP, YPP)
      EP = EP + EP1
      ET = ET + ET1
    2 IF (CP .EQ. "C") GO TO 22
      EYZX(J) = CABS(EP)
      EYZY(J) = CABS(ET)
      GO TO 3
   22 EYZY(J) = CABS(EP*C(IPSI) + ET*S(IPSI))
      IPSI = MOD(J-1,8) + 1
    3 CONTINUE
      CALL URESET
      A1 = 0.
      A2 = 0.
      A3 = 0.
      A4 = 0.
      DO 5 J = 1, LIMIT
      A1 = AMAX1(A1, EXZX(J))
      IF (CP .NE. "C") A2 = AMAX1(A2, EXZY(J))
      IF (CP .NE. "C") A3 = AMAX1(A3, EYZX(J))
    5 A4 = AMAX1(A4, EYZY(J))
      A = AMAX1 (A1, A2, A3, A4)
      CALL UPEN (0., 0.)
    7 CALL UERASE
      CALL UDAREA (0.4, 5.119, 0.4, 5.119)
      CALL UWINDO (-1., 1., -1., 1.)
      DO 8 J = 1, 5
    8 CALL UCRCLE (0., 0., 0.2 * J)
      CALL USET ("POLAR")
      DO 9 J = 1, 36
      ANGLE = J * 10
      CALL UMOVE (0.2, ANGLE)
    9 CALL UPEN (1., ANGLE)
      DO 10 J = 1, 4
      ANGLE = J * 90
      CALL UMOVE (0., 0.)
   10 CALL UPEN (0.2, ANGLE)
      CALL USET ("LINE")
```

```
      AA = A
      IF (IQ .EQ. "Y") AA = A1
      CALL UMOVE (EXZX(1)/AA,90.)
      DO 11 J = 1, LIMIT
      ANGLE = (DENSE - J) * FACT
   11 CALL UPEN (EXZX(J)/AA, ANGLE)
      IF (IQ .EQ. "Y") AA = A3
      CALL UMOVE (EYZY(1)/AA,90.)
      DO 12 J = 1, LIMIT
      ANGLE = (J + DENSE - 2) * FACT
   12 CALL UPEN (EYZY(J)/AA, ANGLE)
      IF (IQ .EQ. "Y") AA = A2
      IF (CP .EQ. "C") GO TO 120
      CALL USET ("RECT")
      CALL UMOVE (0.8, -0.8)
      CALL UPEN (1.0, -0.8)
      CALL USET ("POLAR")
      CALL USET ("DASHLINE")
      CALL UPSET ("SETDASH", 5212.)
      CALL UMOVE (EXZY(1)/AA,90.)
      DO 13 J = 1, 181
      ANGLE = (91 - J)
   13 CALL UPEN (EXZY(J)/AA, ANGLE)
      IF (IQ .EQ. "Y") AA = A4
      CALL UMOVE (EYZX(1)/AA,90.)
      DO 14 J = 1, 181
      ANGLE = (J + 89)
   14 CALL UPEN (EYZX(J)/AA, ANGLE)
      CALL USET ("RECT")
      CALL UMOVE (0.8, -0.9)
      CALL UPEN (1.0, -0.9)
      CALL UDAREA (0., 6., 0., 5.119)
      CALL UPRINT (0.76, -0.688, IO)
      CALL UPRINT (0.76, -0.768, IO)
      CALL UPRINT (0.76, -0.688, IDASH)
      CALL UPRINT (0.76, -0.768, ISLASH)
      GO TO 121
  120 CALL USET ("TEXT")
      CALL USET ("RECT")
      CALL UDAREA (0., 6., 0., 5.119)
  121 CALL UPRINT (-1.0, 0., IYZ)
      CALL UPRINT (+0.76, 0., IXZ)
      CALL UPRINT (-0.40, -1.0, ID)
      CALL USET ("LINE")
      ENCODE (11,16,FREQ) F                                        N/S
   16 FORMAT ("F = ",F6.1,";")
      CALL UPRINT (0.60,-1.0,FREQ)
      IF (NORM .NE. 2) GO TO 15
      CALL UFLUSH
      PRINT *, "^\^>^&                                              N/S
      CALL UPAUSE
      RETURN
   15 CALL UREAD (-1., -1., KQ, 1., FLAG)
      IF (KQ .EQ. "S") NORM = 1
      IF (KQ .EQ. "M") NORM = 0
      IF (KQ .EQ. "A") NORM = 2
      IF (KQ .EQ. "R") GO TO 7
      IF (KQ .EQ. "T") ANS = 3
      CALL UERASE
      RETURN
      END
```

```
      SUBROUTINE VPLTS (F, Z11, Z12, Z22, IACC)
C
C     ******************************************************************
C     *                                                                *
C     *  PURPOSE:  This routine plots the "s" parameters of a two port *
C     *            microstrip antenna using the input values of the    *
C     *            open circuit parameters.  It uses the software of the GCS *
C     *            system.                                             *
C     *                                                                *
C     *  PARAMETERS:  F is the frequency in MHz.                       *
C     *               Z11, Z12, and Z22 are the respective open circuit *
C     *                   parameters of the microstrip antenna (input). *
C     *               IACC is set equal to zero when data is being     *
C     *                     acculmulated by the subroutine for later plotting. *
C     *                     It is set to unity when the acculmulated data is *
C     *                     to acctually be plotted.                   *
C     *                                                                *
C     *  OPTIONS:  At the end of each plot, one may input either a blank *
C     *            character or an "R".  The latter causes the system to *
C     *            replot the graph.                                   *
C     *                                                                *
C     ******************************************************************
C
      COMPLEX S11(100), S12(100), S22(100), Z11, Z12, Z22
      DIMENSION ID(3)
      INTEGER ONEONE, ONETWO, TWOTWO, S
      COMMON /JID/ ID
      COMMON /I1/ A, B, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PDO2A, TPXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      COMMON /DELTA/ DELTA
      S = "S;"
      IX = "X;"
      IO = "O;"
      IS = "+;"
      IC = "*;"
      ONEONE = " 11;"
      ONETWO = " 12;"
      TWOTWO = " 22;"
      ID(3) = ";"
      IF (IACC .EQ. 1) GO TO 5
      CALL VZTOS (Z11, Z12, Z22, S11(K), S12(K), S22(K))
      IF (K .GT. 1) GO TO 3
      Q = 1 / DELTA
      CALL DATE (ID(1))
      CALL TIME (ID(2))
      WRITE (3,1) A, B, T, D, XP, YP, XPP, YPP, DIEL, LOSS,
     *            SIGM, F0, DELTAF, Q, GAIN, ID(1), ID(2)
    1 FORMAT("1",6X,"T W O   P O R T   R E C T A N G U L A R   M I C R O
     1 S T R I P",/,7X,"- - -  - - - -  - - - - - - - - - - -  - - -
     2- - - - - - -",/,"0",6X,"Dimensions (a X b X t) ......
     3..............(",    F4.1," X ",F4.1," X ",F4.2,") cm",/,7X,"F`
     4Eed data: (1) Width .......................",F4.2," cm
     5",/,18X,"(2) Port one ................... (",F4.1,",",F4.1,"
     6) cm",/,18X,"(3) Port two ................... (",F4.1,",",
     7F4.1,") cm",/,7X,"Electrical parameters: (1)
     8Dielectric ..... ",F5.2,/,30X,"(2) Loss tangent
     9 ... ",F7.5,/,30X,"(3) Conductivity ... ",F5.1," KMho
     *s/Cm",/,7X,"Center frequency ....................
     1..... ",F7.1," MHz",/,7X,"Frequency increment ..
     2..................... " ,F7.1," MHz",/,7X,"Quality fact
     3or ........................... ",F5.1,/,7X,"Gain ...........
     4........................... ",F4.1," dB",/,7X,"Date/time .
     5.............................. ",2A10,/,"0",6X,"Frequenc`
     6Y",11X,"S",16X,"S",16X,"S",/,9X,"(MHz)",14X,"11",15X,"12",15X,"12
     7",/,"0")
    3 WRITE (3,4) F, S11(K), S12(K), S22(K)
    4 FORMAT (7X,F7.1,6X,3("(",F6.3,",",F6.3,")",2X))
      RETURN
```

```
    5 CALL URESET
      CALL UERASE
      NO2 = NFREQ/2 + 1
      NO21 = NO2 + 1
      CALL USET ("LINE")
      CALL UWINDO (-1.,1.,-1.,1.)
      CALL UDAREA (0.4, 5.119, 0.4, 5.119)
      CALL UCRCLE (0., 0., 1.)
      CALL UMOVE (0.,1.)
      CALL UARC (1.,1.,90.)
      CALL UARC (1.,-1.,90.)
      CALL UCRCLE (0.5,0.0,0.5)
      CALL UMOVE (-1.0,0.0)
      CALL UPEN (1.0,0.0)
      CALL USET("DASHLINE")
      CALL UPSET("SETDASH",5414.)
      CALL UCRCLE (0.,0.,0.5)
      CALL USET("LINE")
      CALL USET ("NX")
      CALL USET ("SOFT")
      CALL UPSET ("HORIZONTAL", 0.03)
      CALL UPSET ("VERTICAL", 0.03)
      DO 6 J = 1, NFREQ
      IF (J .EQ. NO2) CALL USET ("N*")
      IF (J .EQ. NO21) CALL USET ("NX")
    6 CALL UPEN (REAL(S11(J)), AIMAG(S11(J)))
      CALL UPRINT (0.75, -0.75, IX)
      CALL USET ("NO")
      DO 7 J = 1, NFREQ
      IF (J .EQ. NO2) CALL USET ("N*")
      IF (J .EQ. NO21) CALL USET ("NO")
    7 CALL UPEN (REAL(S12(J)), AIMAG(S12(J)))
      CALL UPRINT (0.75, -0.85, IO)
      CALL USET ("N+")
      CALL UPSET ("VERTICAL", 0.06)
      CALL UPSET ("HORIZONTAL", 0.04)
      DO 8 J = 1, NFREQ
      IF (J .EQ. NO2) CALL USET ("N*")
      IF (J .EQ. NO21) CALL USET ("N+")
    8 CALL UPEN (REAL(S22(J)), AIMAG(S22(J)))
      CALL UPRINT (0.75, -0.95, IS)
      CALL USET ("HARD")
      CALL UPRINT (0.85, -0.80, ONEONE)
      CALL UPRINT (0.85, -0.775, S)
      CALL UPRINT (0.85, -0.975, S)
      CALL UPRINT (0.85, -0.875, S)
      CALL UPRINT (0.85, -0.90, ONETWO)
      CALL UPRINT (0.85, -1., TWOTWO)
      CALL UDAREA (0.,5.5,0.,5.5)
      CALL UPRINT (-0.47,-1.0,ID)
      CALL UREAD (-1., -1., IQ, 1., F)
      IF (IQ .NE. " ") GO TO 5
      CALL UERASE
      RETURN
      END
```

```
      SUBROUTINE VPLTZ (Z, F, IACC)
C
C     ****************************************************************
C     *                                                              *
C     * PURPOSE:  This program accumulates impedance data, outputs in tab- *
C     *           ulated form, and then plots in one of three optional ways: *
C     *           (a) Smith chart, (b) Rectangular G-B plot, or (3) magnitude*
C     *           of reflection coefficient vs frequency.            *
C     *                                                              *
C     * PARAMETERS:  Z is the complex impedance to be plotted.       *
C     *              F is the frequency at which Z was determined.   *
C     *              IACC is 2, data is accumulated for future plotting, *
C     *              while if IACC is 1, the data is plotted.        *
C     *                                                              *
C     ****************************************************************
C
      COMPLEX Y, GAMMA, Z
      INTEGER P, STRING(4)
      DIMENSION ID(3),FREQ(100),G(100),B(100),IF0(2),IINC(2),IDIM(2)
      COMMON /JID/ ID
      COMMON /LDID/ STRING
      COMMON /I1/ A,BB, T, D, DIEL, LOSS, SIGM, P, XP, YP, XPP, YPP, L,
     *            F0, NFREQ, K0, TWOPI, PDO2A, TPXPOA, BOA, BAND, PI,
     *            ETA0, K, GAIN, DELTAF
      COMMON /DELTA/ DELTA
      ID(3) = ";"
      IF (IACC .EQ. 1) GO TO 10
      NO2 = NFREQ/2 + 1
      NO21 = NO2 + 1
      IF (K .GT. 1) GO TO 3
      Q = 1 / DELTA
      CALL DATE (ID(1))
      CALL TIME (ID(2))
      ENCODE (17, 202, IDIM) A, BB                                      N/S
  202 FORMAT (F5.2," X ",F5.2," CM;")
      ENCODE (17, 200, IF0) F0                                          N/S
  200 FORMAT ("F0  = ",F6.1," MHZ;")
      ENCODE (16, 201, IINC) DELTAF                                     N/S
  201 FORMAT ("INC = ",F5.1," MHZ;")
      WRITE (3,1) A, BB, T, D, XP, YP
      IF (P .EQ. 2) WRITE (3,999) XPP, YPP, STRING
      WRITE (3,1000) DIEL,LOSS,SIGM,F0,DELTAF,Q,GAIN,ID(1),ID(2)
    1 FORMAT("1",6X,"T W O   P O R T   R E C T A N G U L A R   M I C R O
     1 S T R I P",/,7X,"- - -   - - - -   - - - - - - - - - - -   - - -
     2- - - - - - -",/,"0",6X,"Dimensions (a X b X t) ......
     3.............(",   F5.2," X ",F5.2," X ",F4.2,") cm",/,7X,"F
     4Eed data: (1) Width .................... ",F4.2," cm
     5",/,18X,"(2) Port one ................... (",F5.2,",",F5.2,"
     6) cm")
  999 FORMAT(18X,"(3) Port two .................. (",
     1F5.2,",",F5.2,") Cm",/,
     27X,"Load description: ....................... ",
     34A10)
 1000  FORMAT(        7X,"Electrical parameters: (1)
     8Dielectric ..... ",F5.2,/,30X,"(2) Loss tangent
     9 ... ",F7.5,/,30X,"(3) Conductivity ... ",F5.1," KMho
     *s/Cm",/,7X,"Center frequency ..................
     1..... ",F7.1," MHz",/,7X,"Frequency increment ..
     2.................... ",F7.1," MHz",/,7X,"Quality fact
     3or .......................... ",F5.1,/,7X,"Gain ...........
     4......................... ",F4.1," dB",/,7X,"Date/time ..
     5.............................. ",2A10,/,"0",6X,"Frequenc
     6Y",11X,"Z",/,9X,"(MHz)",
     7/,"0")
    3 WRITE (3,4) F, Z
    4 FORMAT (7X,F7.1,6X,"(",F6.2,","F7.2,")")
      FREQ(K) = F - F0
      Y = 50./Z
      G(K) = REAL(Y)
```

```
      B(K) = AIMAG(Y)
      RETURN
   10 CALL URESET
      PRINT *,"^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*^*"
      PRINT *,"^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!"
      PRINT *,"^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!"
      PRINT *,"^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!^!"
      PRINT *,"RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, ",
     1         "OR V)",
      READ 2, KODE
    2 FORMAT (A1)
      IF (EOF(2) .NE. 0) RETURN
      IF (KODE .EQ. "S") KKODE = 1
      IF (KODE .EQ. "R") KKODE = 2
      IF (KODE .EQ. "V") KKODE = 3
      GO TO (5, 12, 15), KKODE
    5 CALL UERASE
      CALL USET ("LINE")
      CALL UWINDO (-1.,1.,-1.,1.)
      CALL UDAREA (0.4, 5.119, 0.4, 5.119)
      CALL UCRCLE (0., 0., 1.)
      CALL UMOVE (0.,1.)
      CALL UARC (1.,1.,90.)
      CALL UARC (1.,-1.,90.)
      CALL UCRCLE (0.5,0.0,0.5)
      CALL UMOVE (-1.0,0.0)
      CALL UPEN (1.0,0.0)
      CALL USET("DASHLINE")
      CALL UPSET("SETDASH",5414.)
      CALL UCRCLE (0.,0.,0.5)
      CALL USET("LINE")
      CALL USET ("NX")
      CALL USET ("SOFT")
      CALL UPSET ("HORIZONTAL", 0.02)
      CALL UPSET ("VERTICAL", 0.02)
      DO 6 J = 1, NFREQ
      Y = CMPLX (G(J),B(J))
      GAMMA = (1-Y)/(1+Y)
      IF (J .EQ. NO2) CALL USET ("N*")
      IF (J .EQ. NO21) CALL USET ("NX")
    6 CALL UPEN (REAL(GAMMA), AIMAG(GAMMA))
      CALL USET ("HARD")
      CALL UDAREA (0.,5.5,0.,5.5)
      CALL UPRINT (-0.40,-1.0,ID)
      CALL USET ("SOFT")
      CALL USET ("ITALLICS")
      CALL UPSET ("HORIZONTAL", 0.03)
      CALL UPSET ("VERTICAL", 0.05)
      CALL UPRINT (0.4, -0.85, IFO)
      CALL UPRINT (0.4, -0.92, IINC)
      CALL UPRINT (0.4, -0.99, IDIM)
      CALL UERASE
   14 CALL UREAD (0., 0., KODE, 1., FLAG)
      IF (KODE .EQ. "R") GO TO 10
      GO TO 9
   12 RMAX = 0.
      XABSMX = 0.
      DO 13 J = 1, NFREQ
      Z = 1 / CMPLX (G(J), B(J))
      XABSMX = AMAX1 (ABS(AIMAG(Z)), XABSMX)
   13 RMAX = AMAX1(RMAX, REAL(Z))
      ABSMAX = AMAX1 (RMAX, XABSMX)
      DEC = ALOG10(ABSMAX)
      IDEC = DEC
      IF (DEC .LT. 0.) IDEC = IDEC - 1
      DECADE = 10. ** IDEC
      IDIGIT = ABSMAX / DECADE + 1
      WINDOW = IDIGIT * DECADE
      CALL UWINDO (0., 2.*WINDOW, -WINDOW, WINDOW)
```

```
      TICK = DECADE
      IF (IDIGIT .LT. 7) TICK = 0.5 * DECADE
      IF (IDIGIT .LT. 3) TICK = 0.2 * DECADE
      CALL UPSET ("TICX", TICK)
      CALL UPSET ("TICY", TICK)
      CALL UERASE
      CALL UDAREA (0.4, 5., 0.4, 5.)
      CALL UPSET ("YLABEL","X;")
      CALL UPSET ("XLABEL","R;")
      CALL USET ("GRIDAXIS")
      CALL USET ("XBOTH")
      CALL USET ("YBOTH")
      CALL USET ("POINT")
      CALL USET("OWNSCALE")
      CALL UAXIS (0., 2.*WINDOW, -WINDOW, WINDOW)
      CALL USET("LINE")
      CALL USET ("NX")
      CALL USET ("SOFT")
      CALL UPSET ("HORIZONTAL", 0.02 * WINDOW)
      CALL UPSET ("VERTICAL", 0.02 * WINDOW)
      DO 130 J = 1, NFREQ
      Z = 1 / CMPLX (G(J), B(J))
  130 CALL UPEN (REAL(Z), AIMAG(Z))
      CALL USET ("HARD")
      CALL UDAREA (0., 5., 0., 5.)
      CALL UWINDO (-1., 1., -1., 1.)
      CALL UPRINT (-0.47,-1.0,ID)
      CALL UPAUSE
      CALL UERASE
      CALL USET ("LINE")
      GO TO 14
   15 CALL UERASE
      CALL UDAREA (0.4, 5.4, 0.4, 5.4)
      CALL USET ("GRIDAXES")
      CALL USET ("XBOTH")
      CALL USET ("YBOTH")
      CALL UPSET("XLABEL","FREQUENCY - F0;")
      CALL UPSET ("YLABEL","MAGNITUDE OF GAMMA;")
      CALL USET ("AUTO")
      CALL UAXIS (FREQ(1), FREQ(NFREQ), 0.00, 1.00)
      CALL USET("SOFT")
      CALL UPSET("HORIZONTAL",0.02 * (FREQ(NFREQ) - FREQ(1)))
      CALL UPSET("VERTICAL",0.02)
      CALL USET("NX")
      DO 156 J = 1, NFREQ
      Y = CMPLX (G(J),B(J))
      GAMMA = (1-Y)/(1+Y)
  156 CALL UPEN (FREQ(J), CABS(GAMMA))
      CALL USET ("SOFT")
      CALL USET ("ITALLICS")
      CALL UDAREA (0., 7.49, 0., 5.71)
      CALL UWINDO (0., 1., 0., 1.)
      CALL UPSET ("HORIZONTAL", 0.015)
      CALL UPSET ("VERTICAL", 0.03)
      CALL UPRINT (0.7, 0.5, ID)
      CALL UPRINT (0.7, 0.47, IFO)
      CALL UPRINT (0.7, 0.44, IINC)
      CALL UPRINT (0.7, 0.41, IDIM)
      CALL UPAUSE
      CALL UERASE
      GO TO 14
    9 RETURN
      END
```

CHAPTER 3: EXAMPLES

This chapter contains examples of the use of this program to analyze a microstrip antenna. The specific case chosen was that of a nearly square microstrip antenna. This was chosen to illustrate that by making one side of the antenna a small amount larger than the other, and by properly feeding and loading the the antenna with a variable capacitor (such as a varactor), the antenna can be switched from left hand circular polarization to right hand circular polarization. This is consistent with both theory and experiments carried out at the University of Illinois and presented in references [4] and [6]. The output listed below is a copy of the actual graphical data displayed on a graphics terminal by the program. Explanatory remarks have been added to aid the reader.

```
.  a  .  b  . t . d .diel.loss.sigm.p.
?  7.62  7.80 .15 .25 2.62 1.0  270.
.  x'  .  y'  .
?  1.00  3.90
.   f0   .band. Δf .
? 1216.0    10.  2.
Choose an option:
  (1) Plot patterns at all frequencies.
  (2) Plot pattern only at center frequency.
  (3) Plot no patterns
Type option (1, 2, or 3):
? 2
```



```
CP OR LINEAR (TYPE C OR L) ? L

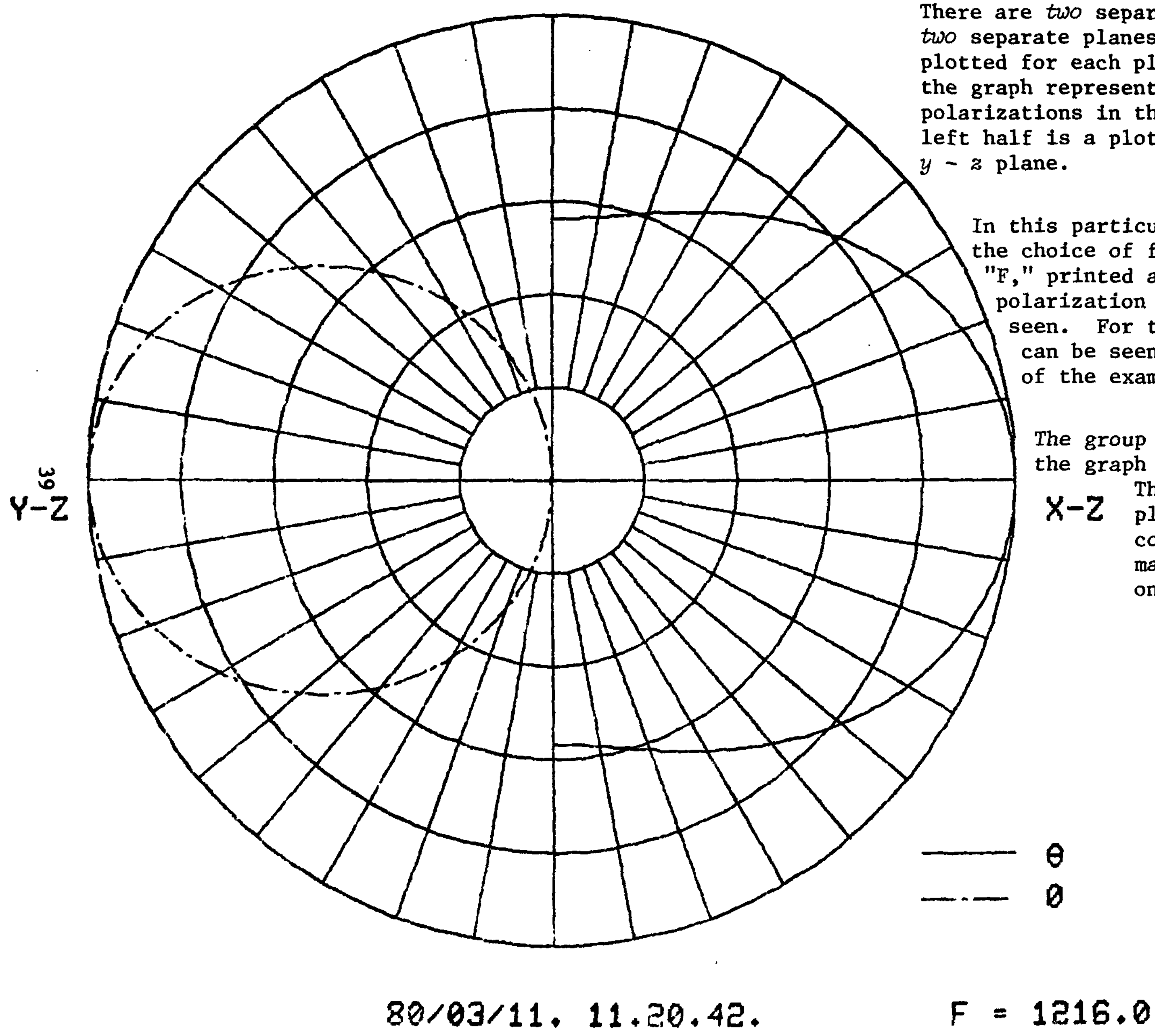
INDIVIDUAL NORMALIZATION (Y OR N)  ? N
```

The option of plotting a pattern at the center frequency was chosen in this case. Additionally, within the plotting routine itself, the options of a linear polarization pattern without individual normalization were chosen.

In this example, a, b, and t are the geometrical parameters (in cm) of the microstrip antenna shown in Fig. 2. The parameter d is the "effective feed width" in cm. The dielectric constant relative to free space is the input under the "diel." The loss tangent of the dielectric (times one thousand) is typed under the "loss." The conductivity of the cladding is under the "sigm" in units of K℧/cm. The parameter, p, is the number of ports (either "1" or "2"). The default value of p is initially unity and its previous value in subsequent computations. The coordinate of the feed point is (x',y') corresponding to (x_1,y_1) in the discussion in Appendix 1. The impedance, and, optionally, the patterns will be computed for frequencies, f, in a range of approximately

$$\left(1 + \frac{\eta}{200}\right) f_0 \geq f \geq \left(1 - \frac{\eta}{200}\right) f_0$$

where η is typed in under "band" (in percentage), and f_0 is typed in under "f0." Computations are always performed at f_0 and at frequencies differing from f_0 within the band by integral multiples of Δf, the input under "Δf."



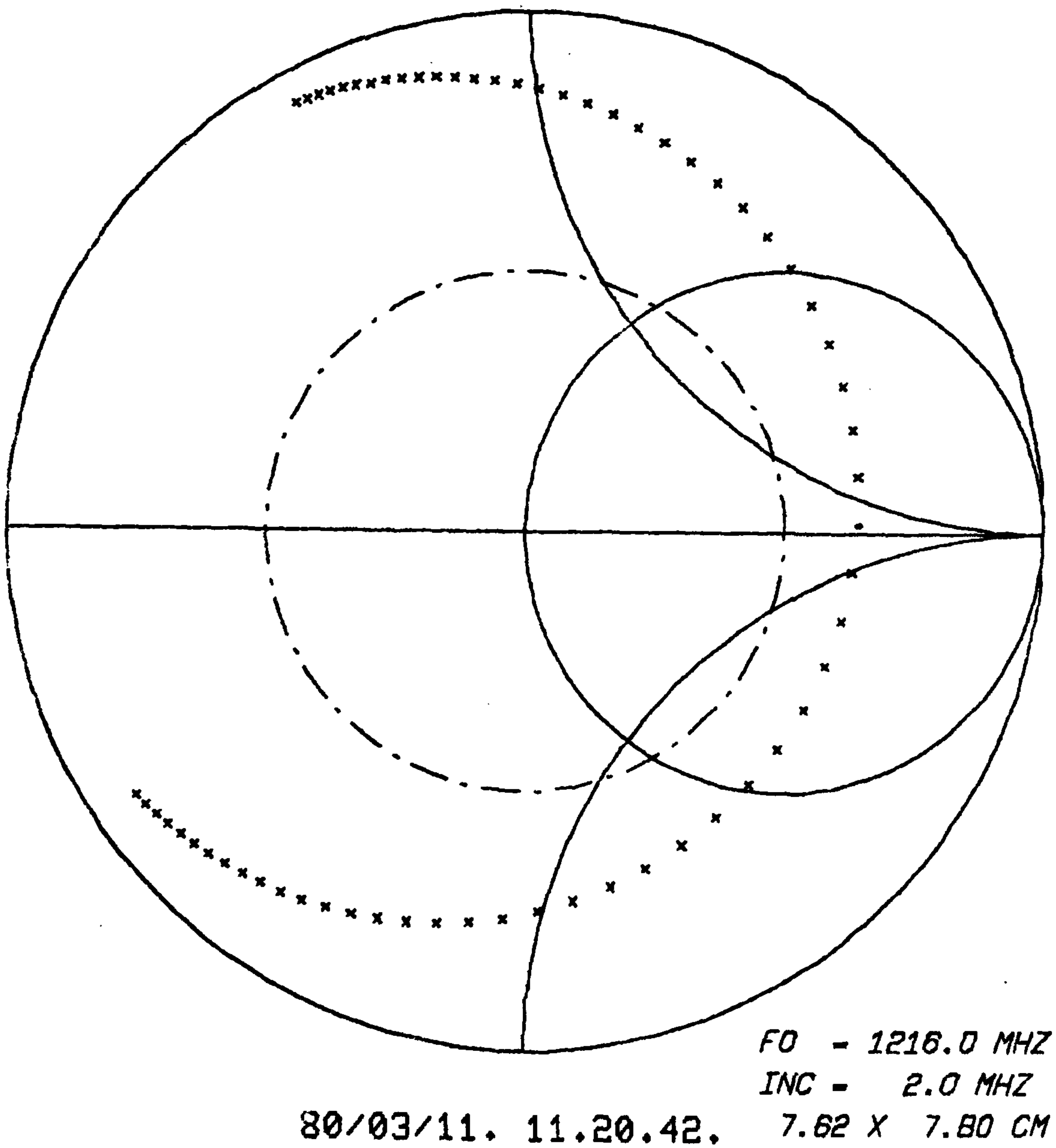
There are *two* separate patterns in each of *two* separate planes. Both E_θ and E_ϕ are plotted for each plane. The right half of the graph represents a plot of these two polarizations in the $x - z$ plane, while the left half is a plot of these patterns in the $y - z$ plane.

In this particular example, because of the choice of feed point and frequency, "F," printed at the bottom, the cross-polarization is so small it cannot be seen. For the case where "cross-pol" can be seen clearly, refer to the end of the example.

The group of numbers directly under the graph is the "date/time-group." This is used to identify the plot with the associated "hard copy" output that is automatically printed. It appears on *all* plots.

```
RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, OR V)? S
```

Here, the system is requesting the input of the desired type of impedance plot. If no plot is desired at all, the user can simply respond with a carriage return. In this case, the user chose a Smith chart plot.



This is a plot of the complex reflection coefficient. That is it is the impedance locus plotted on a Smith chart. The center frequency, f_0 = FO, the increment in frequency between adjacent points in the Smith chart, Δf = INC, and the patch dimensions, $a \times b$, are printed with the plot. The asterisk, "*", is the point corresponding to f_0.

Continue (type Y or N)

? Y

```
 .   a  .  b  . t . d .diel.loss.sigm.p.
?
 .  x' .  y' .
?  3.81  1.00
 .    f0   .band. Δf .
?  1188.0   10.  2.
Choose an option:
  (1) Plot patterns at all frequencies.
  (2) Plot pattern only at center frequency.
  (3) Plot no patterns
Type option (1, 2, or 3):
? 2
```

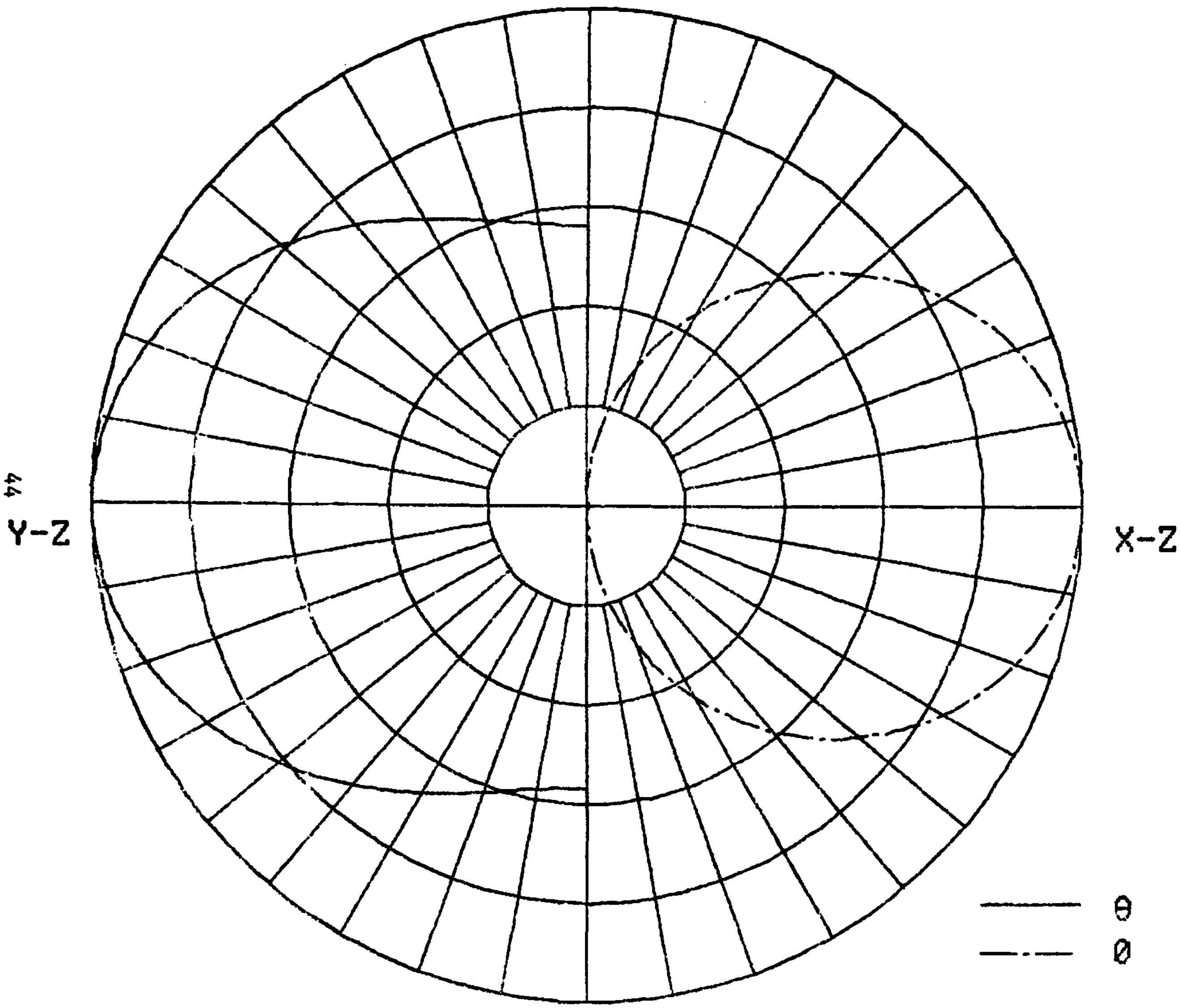
In this implementation, only those parameters which are to be changed from the previous calculation need be input.

43

```
CP OR LINEAR (TYPE C OR L) ? L

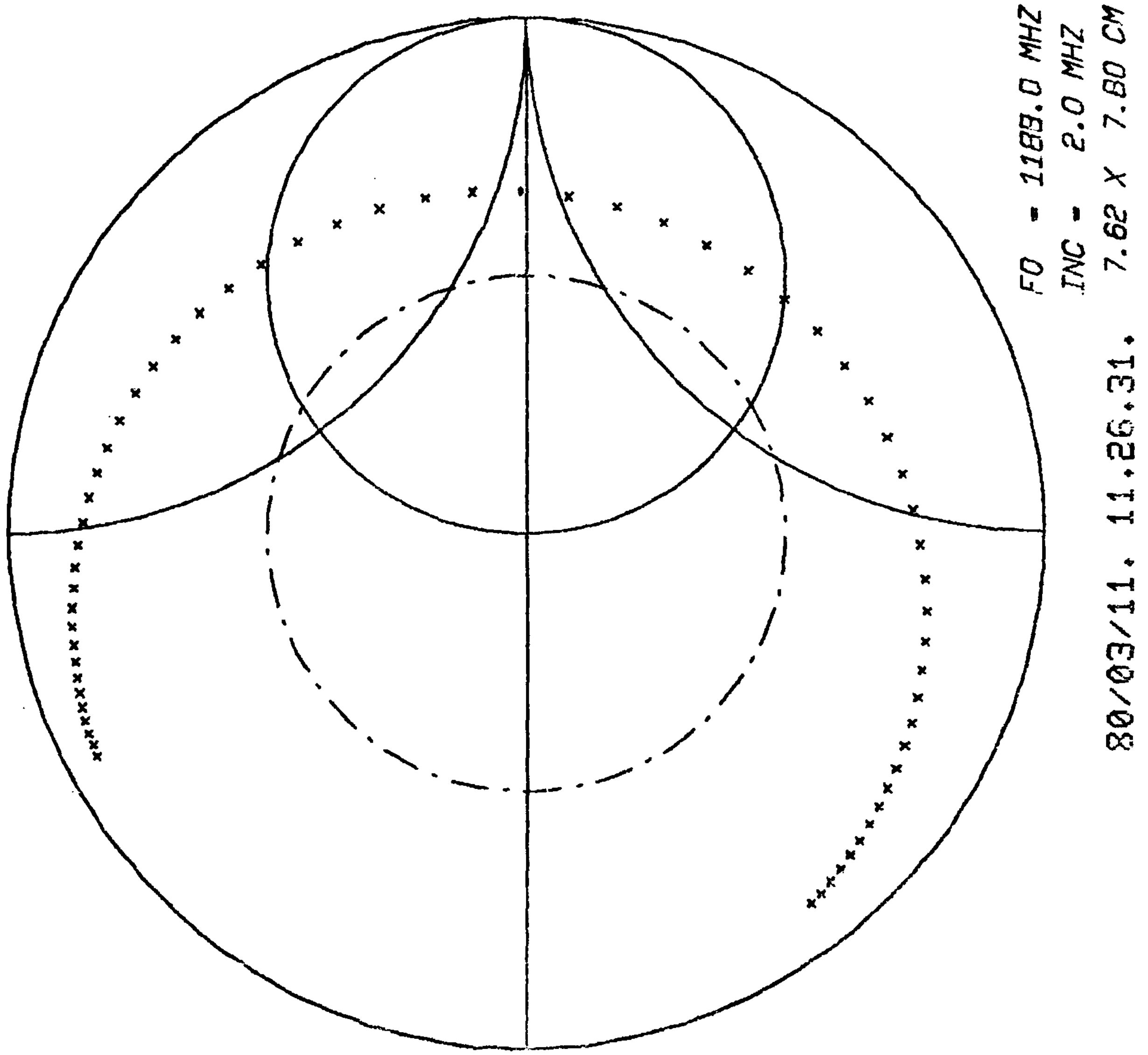
INDIVIDUAL NORMALIZATION (Y OR N)  ? N
```

"Individual normalization," as used here means that all patterns are normalized by their own respective maximum values. Thus, information about the relative importance of cross polarization is lost under this option. The usual response is "N" (for "no"), the default. Under the "N" option, the patterns are all normalized by the same factor. This factor is the maximum of all four patterns.



80/03/11. 11.26.31. F = 1188.0

RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, OR V)? S

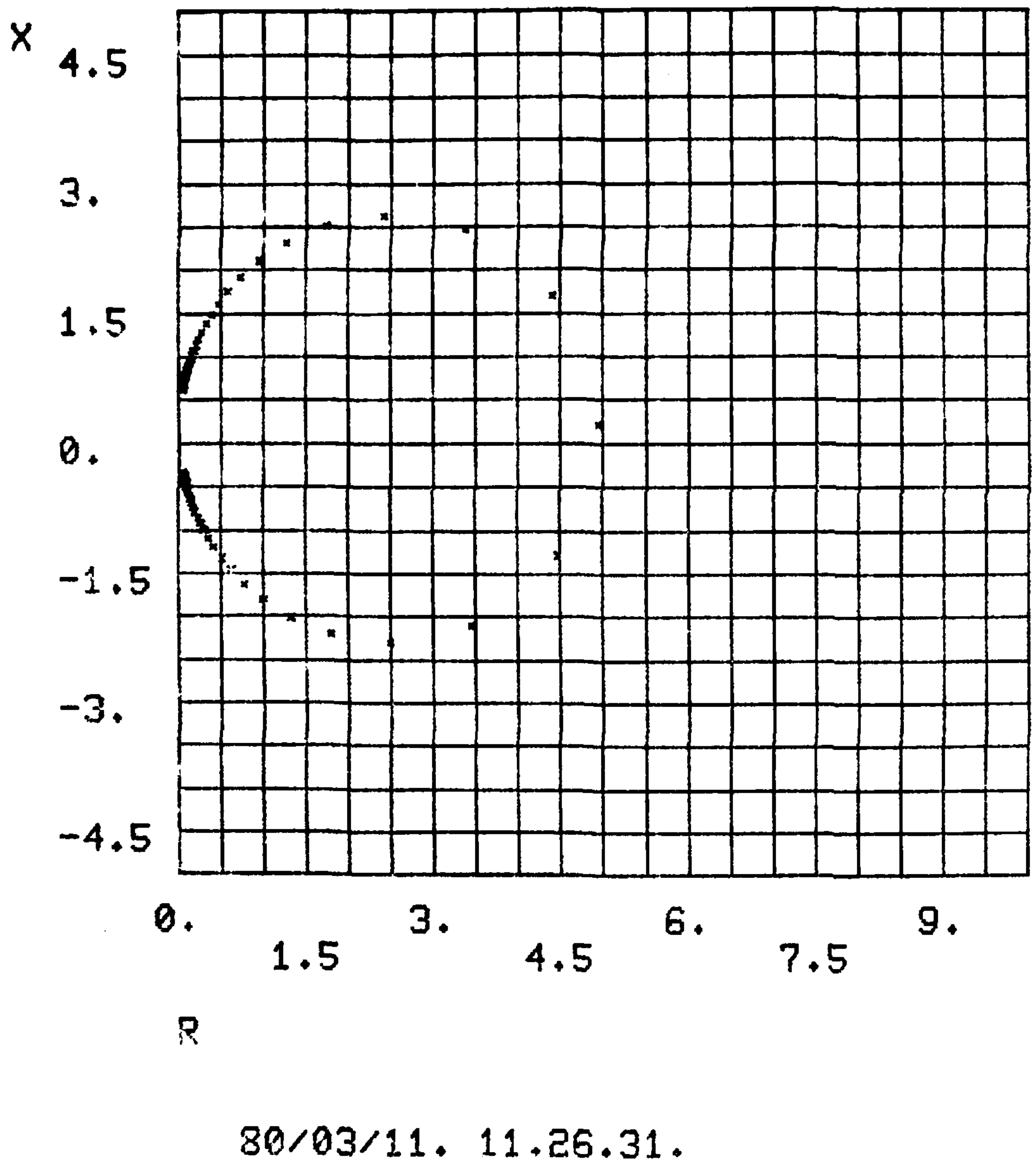

FO = 1188.0 MHZ
INC = 2.0 MHZ
7.62 X 7.80 CM
80/03/11. 11.26.31.

When the computer has completed an impedance plot, the program awaits (with no prompting) the input of a single character from the keyboard. If that character is an "R" (for "replot"), the program will again ask for a choice of the type of impedance plot desired and replot the *same* data. In this case, an "R" was input which caused the message below to be typed.

```
R

RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, OR V)? R
```

This time the user chose to plot in a rectangular system.



This type of graph plots the complex impedance in the impedance, Z, plane with the horizontal axis being Re Z and the vertical axis Im Z.

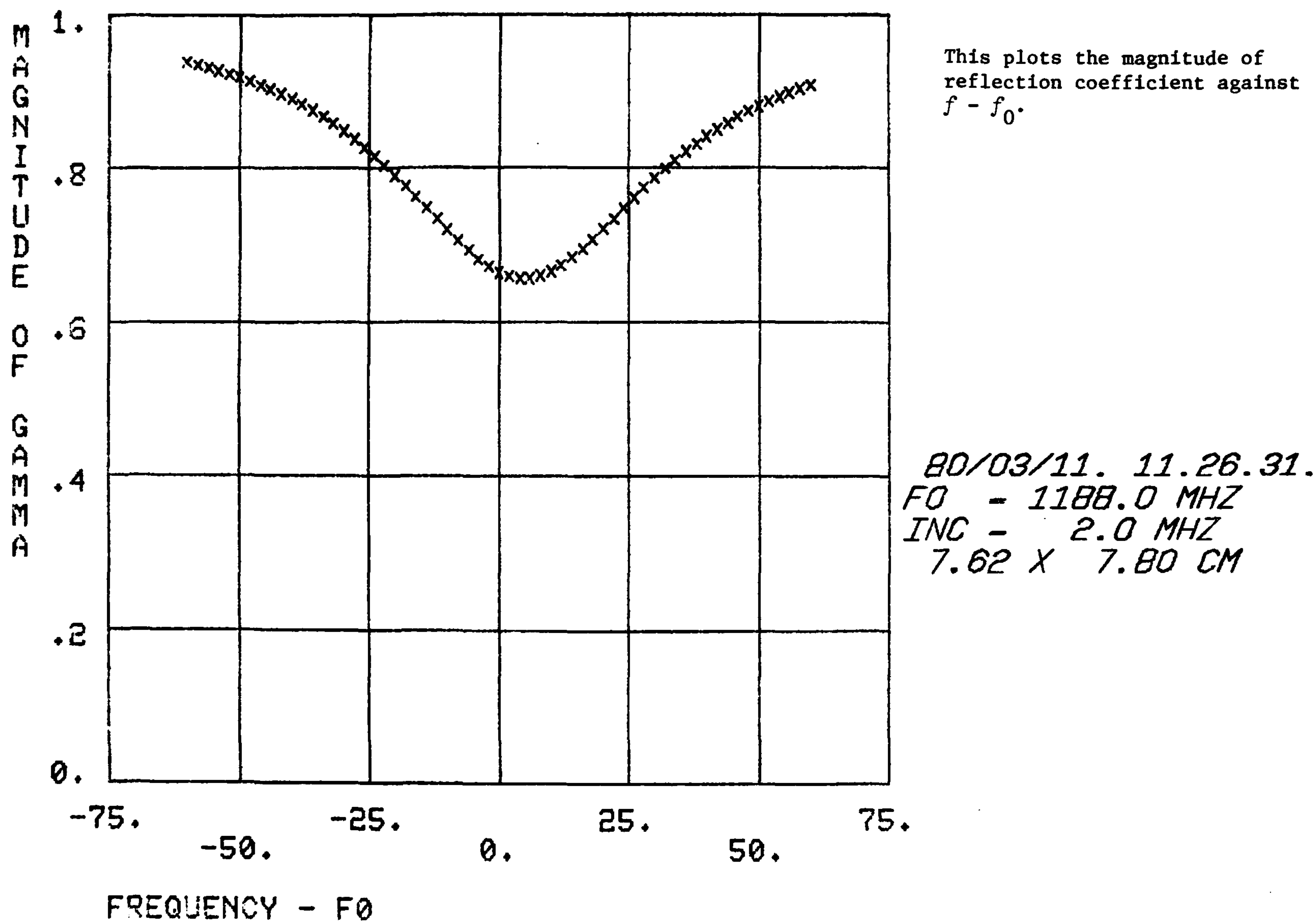
Again, a replot was requested by entering an "R" from the keyboard.

```
R

RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, OR V)? V
```

This time a "*vs* frequency" plot was requested.

This plots the magnitude of reflection coefficient against $f - f_0$.



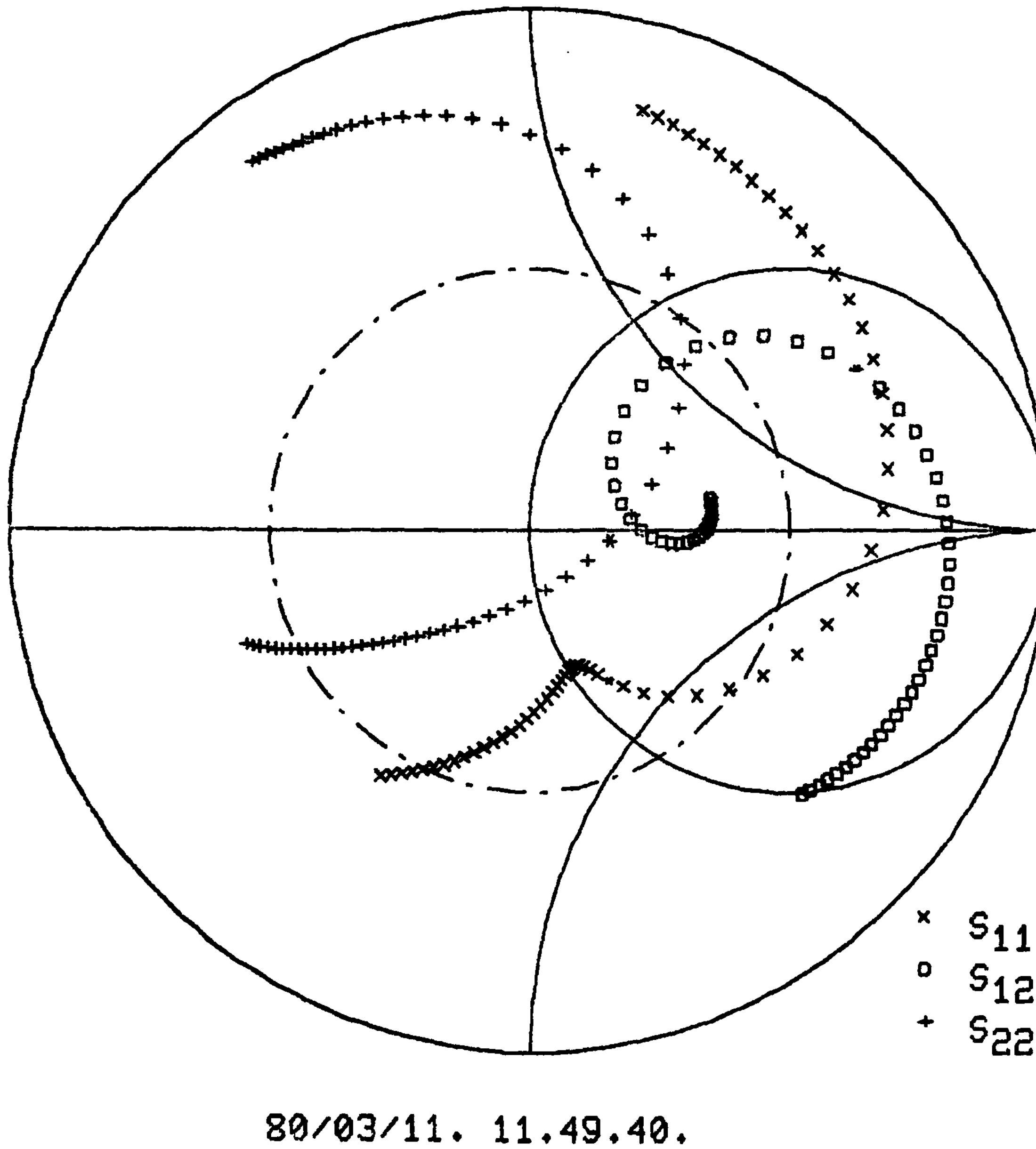
Continue (type Y or N)

? N

```
 .  a  .  b  . t . d .diel.loss.sigm.p.
?  7.62  7.80 .15 .25 2.62 1.0  270. 2
 .  x'  .  y'  .  x"  .  y"  .L.
?  1.00  1.00  1.00  3.90
 .   f0   .band. Δf .
?  1210.    10.   2.
Choose an option:
  (1) Plot patterns at all frequencies.
  (2) Plot pattern only at center frequency.
  (3) Plot no patterns
Type option (1, 2, or 3):
? 3
```

In this case, a second port is added to the existing antenna. This is indicated by placing a "2" under the "P." The coordinate of the second port is (x'',y''). This corresponds to (x_2,y_2) in the discussion in Appendix I. The "L" parameter allows the user to indicate whehter or not there is a load on the second port by placing a "Y" or "N" under it, respectively. The "N" option is assumed initially as default. Thereafter, if L is not specified, it is taken to be its previous value.

(Also note that since this was the beginning of a new run (the previous run having been terminated), all parameters had to be input.)



This is a Smith chart plot of the s-parameters of the unloaded two-port. Again, the location of points corresponding to the center frequency are indicated by "*"'s.

```
Continue (type Y or N)
? Y
```

```
 .   a   .   b   . t . d .diel.loss.sigm.p.
?
 .   x'  .   y'  .  x"  .  y" .L.
?                              Y
 .    f0    .band. Δf  .
?  1194.      4.    1.
Choose an option:
  (1) Plot patterns at all frequencies.
  (2) Plot pattern only at center frequency.
  (3) Plot no patterns
Type option (1, 2, or 3):
? 2
 INPUT CAPACITANCE IN PICOFARADS:  C =   ? 1.35
```

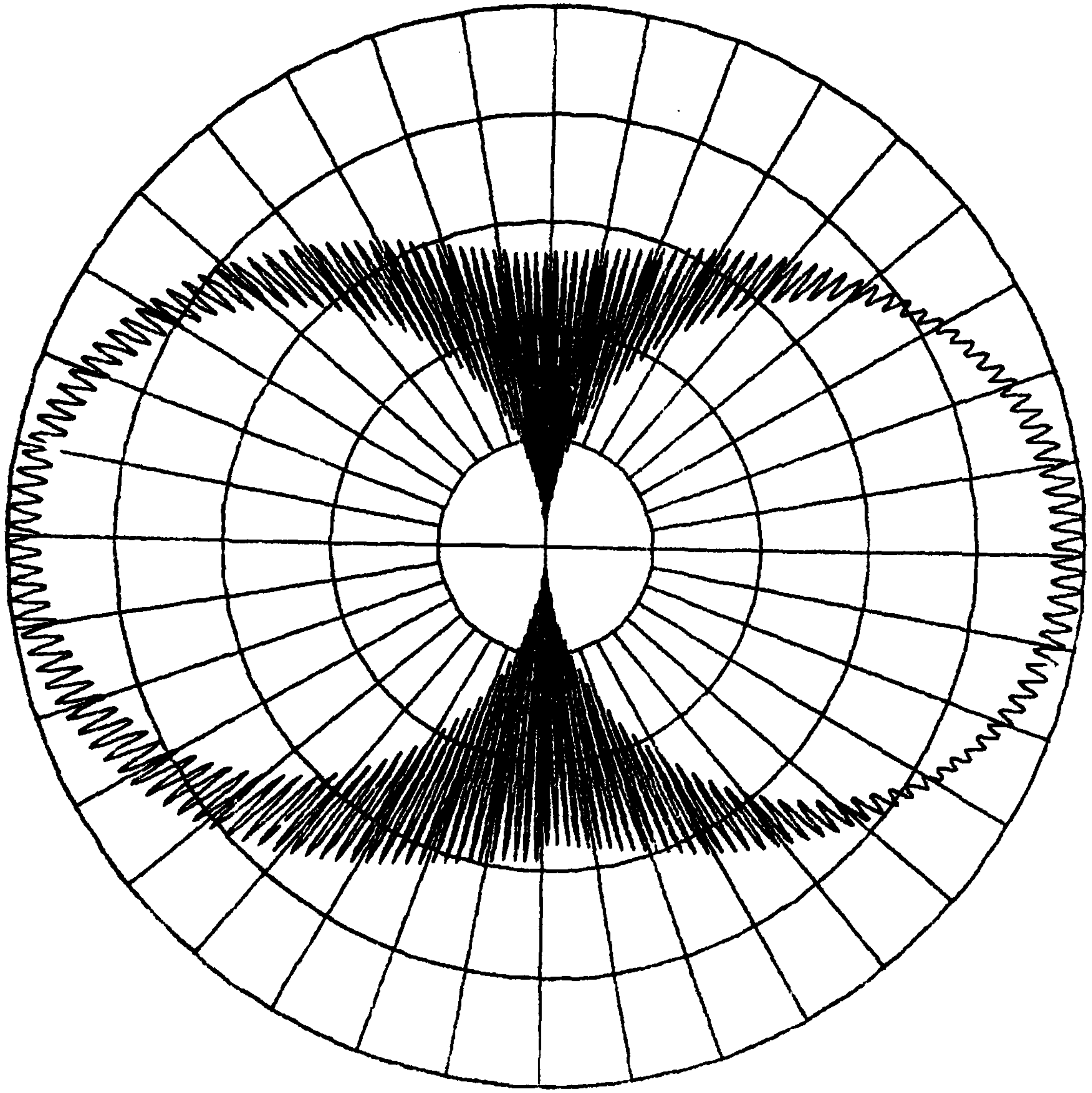
Here, a load was added to the second port as indicated by the "Y" below the "L." The type of load is determined by the user supplied subroutine, VLOAD, which must be loaded with the rest of the program prior to execution.

The particular load used in this example was the capacitor. The subroutine VLOAD was programmed to ask the user to input the capacitance, 1.35 pF in this case.

A plot at the center frequency for this example was also requested with the "C" option.


```
 CP OR LINEAR (TYPE C OR L) ? C
```

Y-Z



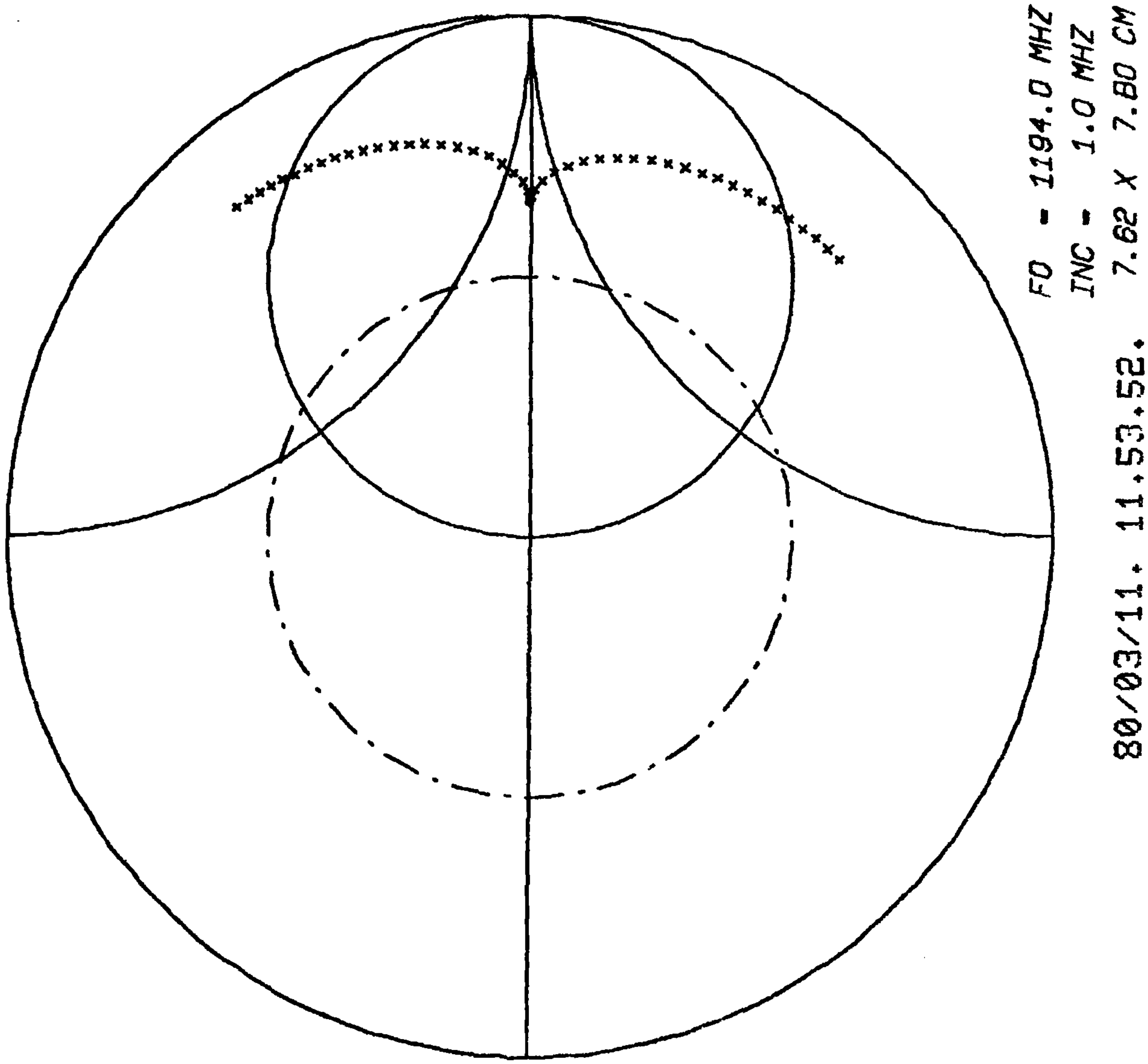
X-Z

These patterns are the simulated responses of a rotating dipole which makes five full rotations per twenty degrees change in elevation angle, θ. Thus, when the antenna is producing circular polarization (CP) in a given direction, the oscillations in the response in that direction disappear.

In this plot, as in the linear polarization plots, the right half of the graph is the pattern in the $x - z$ plane, while the left half is the pattern in the $y - z$ plane.

80/03/11. 11.53.52.   F = 1194.0

RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, OR V)? S

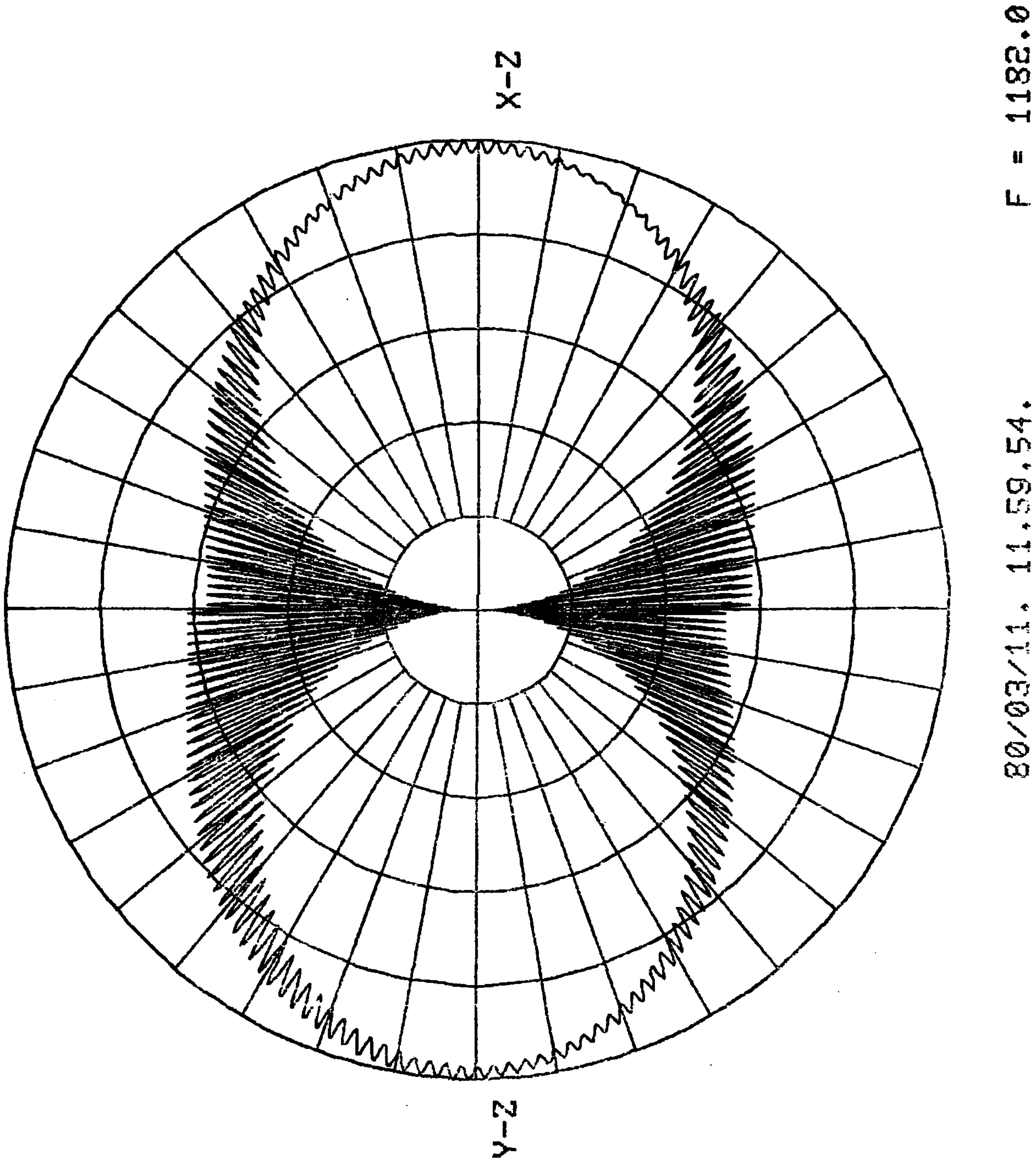

FO = 1194.0 MHZ
INC = 1.0 MHZ
7.62 X 7.80 CM
80/03/11. 11.53.52.

```
 .   a   .   b   . t . d .diel.loss.sigm.p.
?
 .   x'  .   y'  .   x"  .   y"  .L.
?
 .    f0    .band. Δf  .
?  1182.0
Choose an option:
  (1) Plot patterns at all frequencies.
  (2) Plot pattern only at center frequency.
  (3) Plot no patterns
Type option (1, 2, or 3):
? 2
 INPUT CAPACITANCE IN PICOFARADS:  C =  ? 3.1

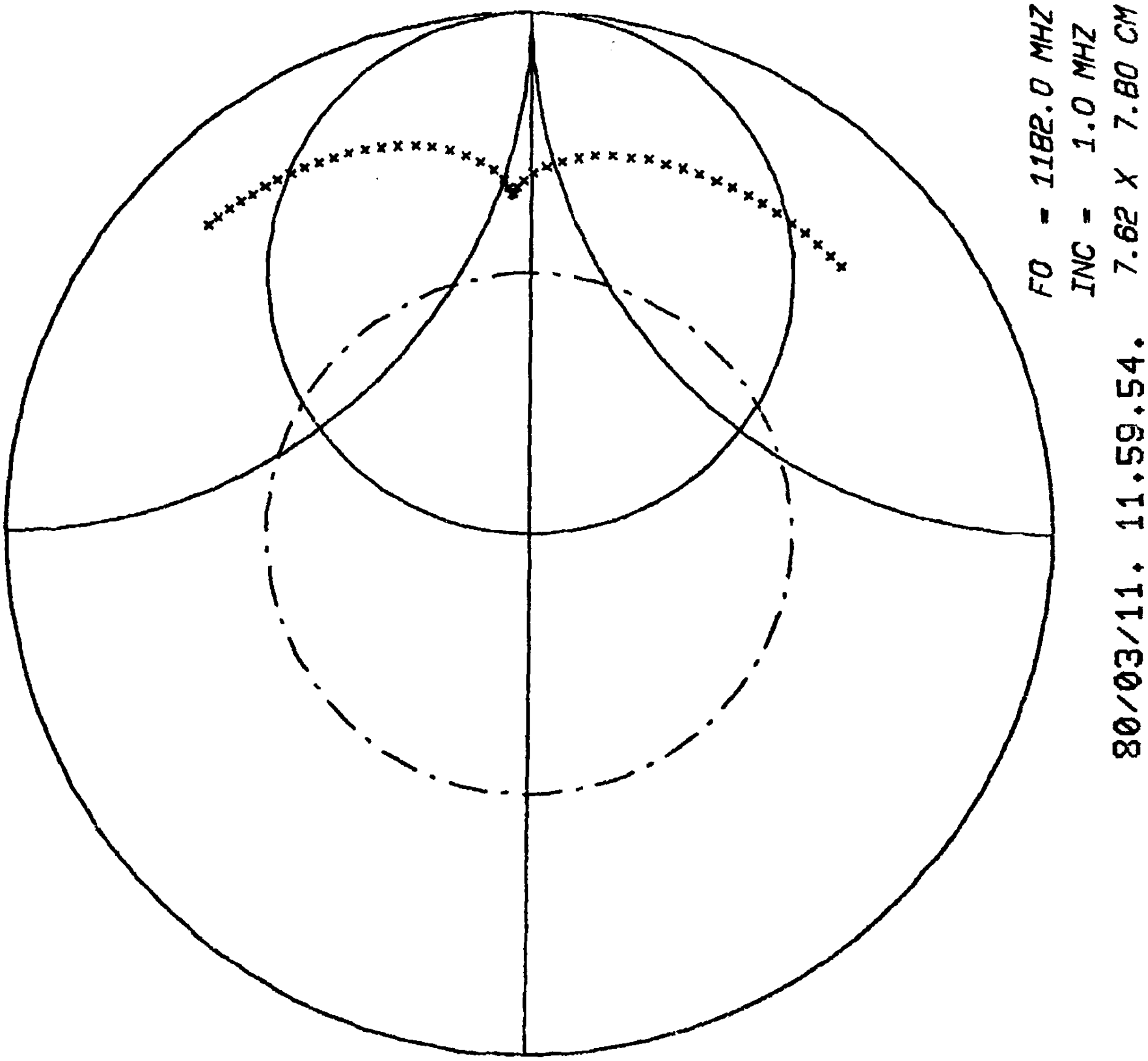


 CP OR LINEAR (TYPE C OR L) ? C
```

In this case, the value of the capacitance has been changed from 1.35 pF to 3.1 pF. This change in load has the effect of reversing the sense of CP.


X-Z
Y-Z
80/03/11. 11.59.54.
F = 1182.0

RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, OR V)? S


FO = 1182.0 MHZ
INC = 1.0 MHZ
7.62 X 7.80 CM
80/03/11. 11.59.54.

Continue (type Y or N)

? Y

```
 .  a  .  b  . t . d .diel.loss.sigm.p.
?
 .  x' .  y' .  x" .  y" .L.
?
 .   f0   .band. Δf .
?           .2  1.
Choose an option:
  (1) Plot patterns at all frequencies.
  (2) Plot pattern only at center frequency.
  (3) Plot no patterns
Type option (1, 2, or 3):
? 1
 INPUT CAPACITANCE IN PICOFARADS:  C =  ? 3.1

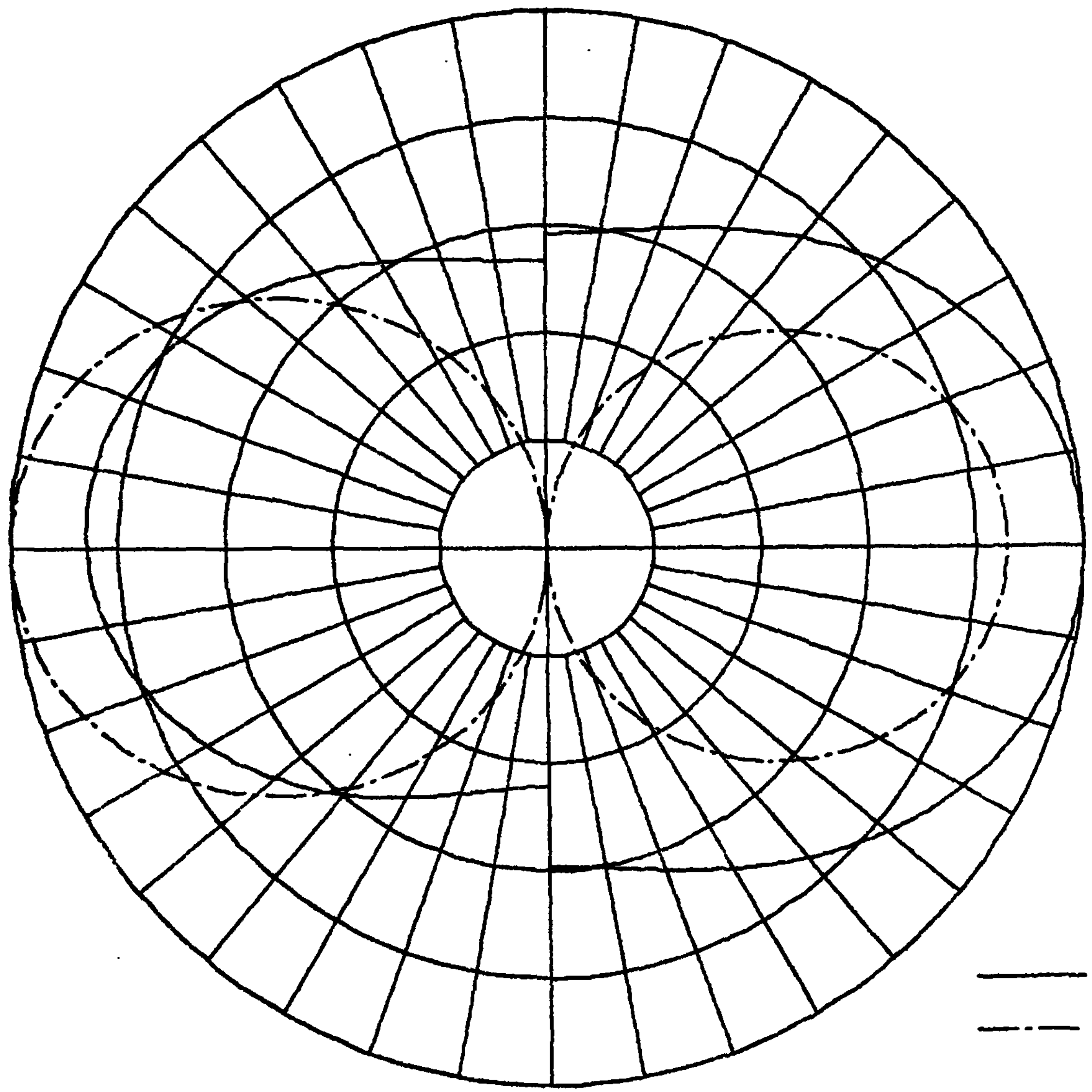

 CP OR LINEAR (TYPE C OR L) ? L

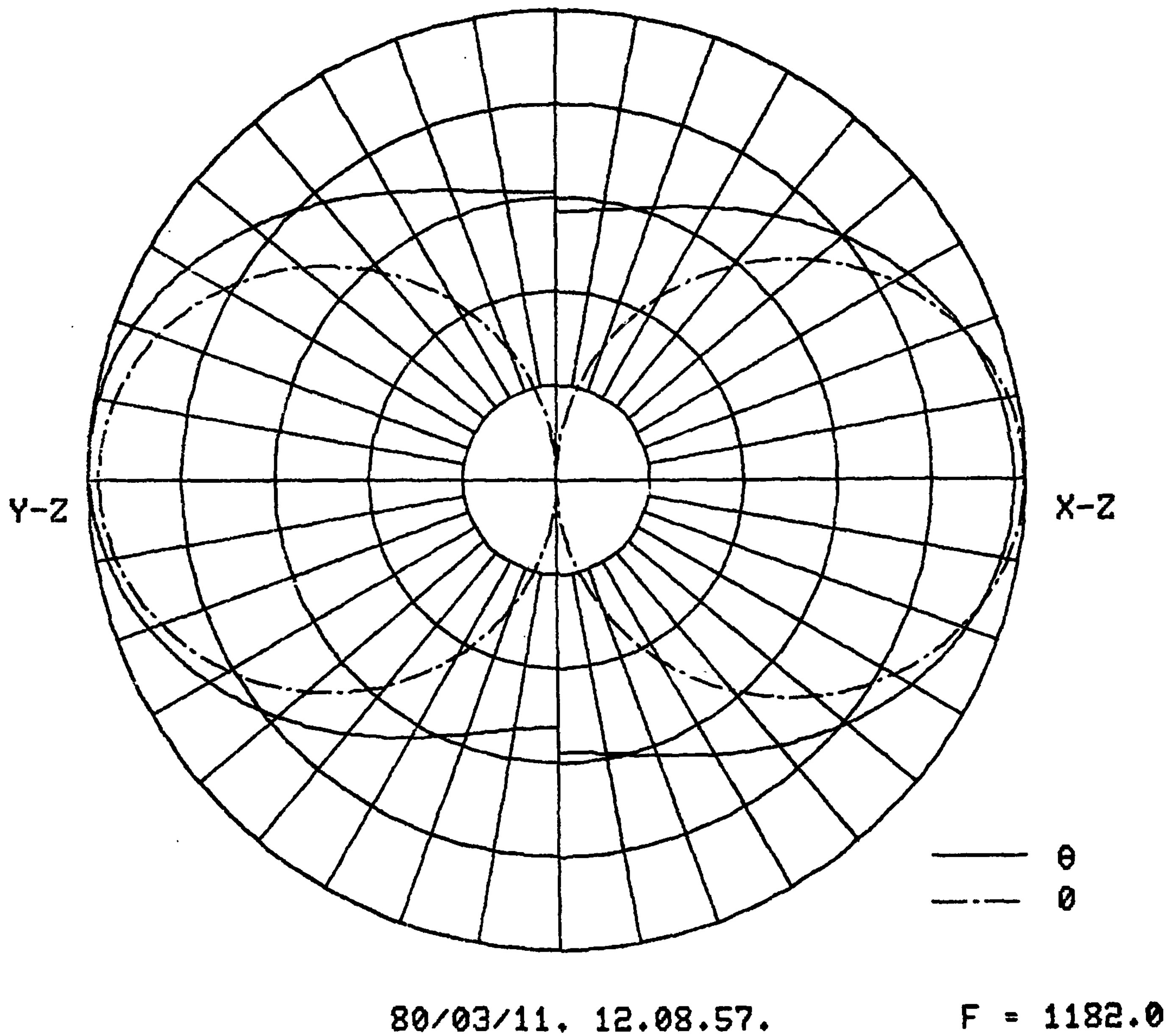
 INDIVIDUAL NORMALIZATION (Y OR N)  ? N
```

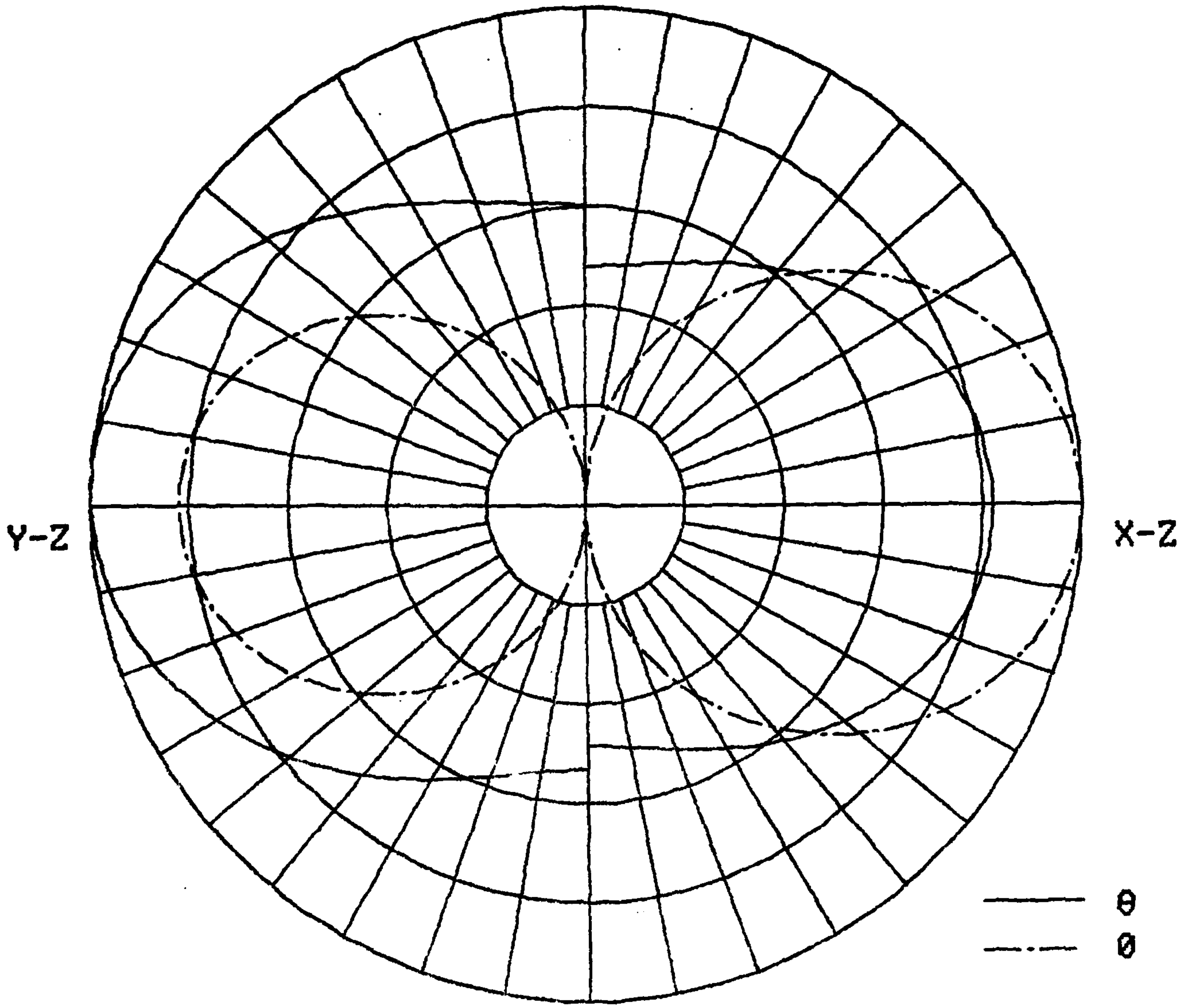
Notice that the band has been narrowed to *0.2% so that only* a few patterns in the vicinity of the point at which CP is produced can be examined. To view all such patterns, the option "1" was selected.

In this case, the linear option has been chosen.

The cross-polarization in this and the subsequent patterns can be clearly seen. Since at broadside (the Z-direction) a *necessary* condition is that the magnitude of E_θ and E_θ be the same, a comparison of these patterns shows that the best CP occurs at f = 1182 MHz.




Y-Z
X-Z
θ
0
80/03/11. 12.08.57.
F = 1182.0



80/03/11. 12.08.57.   F = 1183.0

RECTANGULAR, SMITH CHART, OR VS FREQUENCY PLOT (R, S, OR V)?

No impedance plot was needed since it was previously plotted and so a carriage return was input.

```
T W O   P O R T   R E C T A N G U L A R   M I C R O S T R I P
- - -   - - - -   - - - - - - - - - - -   - - - - - - - - - -

DIMENSIONS (A X B X T) ..................... ( 7.62 X  7.80 X  .15) CM
F ED DATA: (1) WIDTH .......................  .25 C
           (2) PORT ONE ....................  ( 1.00, 3.90) CM
ELECTRICAL PARAMETERS: (1)DIELECTRIC .......  2.62
                       (2) LOSS TANGENT ....   .00100
                       (3) CONDUCTIVITY ....  270.0 KMHOS/CM
CENTER FREQUENCY ...........................  1216.0 MHZ
FREQUENCY INCREMENT ........................     2.0 MHZ
QUALITY FACTOR .............................  95.6
GAIN .......................................  7.0 DB
DATE/TIME ..................................  80/03/11. 11.20.42.
```

FNEQUENC (MHZ)	Z
1154.0	(2.16, 29.61)
1156.0	(2.31, 30.38)
1158.0	(2.48, 31.21)
1160.0	(2.66, 32.09)
1162.0	(2.87, 33.04)
1164.0	(3.10, 34.05)
1166.0	(3.36, 35.14)
1168.0	(3.65, 36.31)
1170.0	(3.97, 37.57)
1172.0	(4.35, 38.95)
1174.0	(4.78, 40.44)
1176.0	(5.27, 42.07)
1178.0	(5.84, 43.86)
1180.0	(6.50, 45.82)
1182.0	(7.28, 47.99)
1184.0	(8.21, 50.40)
1186.0	(9.31, 53.09)
1188.0	(10.65, 56.11)
1190.0	(12.29, 59.51)
1192.0	(14.32, 63.38)
1194.0	(16.88, 67.78)
1196.0	(20.15, 72.84)
1198.0	(24.41, 78.65)
1200.0	(30.08, 85.36)
1202.0	(37.79, 93.03)
1204.0	(48.55, 101.64)
1206.0	(63.89, 110.76)
1208.0	(86.11, 118.98)
1210.0	(117.49, 122.50)
1212.0	(160.57, 112.84)
1214.0	(205.62, 77.21)
1216.0	(226.67, 12.90)
1218.0	(210.59, -53.60)
1220.0	(167.19, -93.17)
1222.0	(124.03, -105.65)
1224.0	(91.04, -103.63)
1226.0	(67.06, -96.12)
1228.0	(51.78, -87.33)
1230.0	(40.48, -78.80)
1232.0	(32.36, -71.20)
1234.0	(26.39, -64.61)
1236.0	(21.90, -58.81)
1238.0	(18.44, -53.76)

These computer printouts contain the geometrical and electrical parameters of the antenna, and the impedance or s-parameters in numerical form. In addition, the "directive gain" of the antenna (more precisely, the gain in the z direction) and the quality factor of the antenna are also printed. Output of this type is created for each antenna analyzed and is directed to file "RESULT." For brevity, however, only output for three of the cases considered in this chapter is included.

To associate a given printout with the graphical output, one simply matches the "date/time" group printed on both.

In this case, the "Z" column represents the driving point impedance of the one port.

```
T W O   P O R T   R E C T A N G U L A R   M I C R O S T R I P
- - -   - - - -   - - - - - - - - - - -   - - - - - - - - - -

DIMENSIONS (A X B X T) ......................  ( 7.6 X  7.8 X  .15) CM
F ED DATA: (1) WIDTH ........................  .25 C
           (2) PORT ONE .....................  ( 1.0, 1.0) CM
           (3) PORT TWO .....................  ( 1.0, 3.9) CM
ELECTRICAL PARAMETERS: (1)DIELECTRIC ........  2.62
                       (2) LOSS TANGENT .....  .00100
                       (3) CONDUCTIVITY .....  270.0 KMHOS/CM
CENTER FREQUENCY ............................  1210.0 MHZ
FREQUENCY INCREMENT .........................  2.0 MHZ
QUALITY FACTOR ..............................  95.9
GAIN ........................................  7.0 DB
DATE/TIME ...................................  80/03/11. 11.49.40.
```

FREUUENC (MHZ)	S_{11}	S_{12}	S_{12}
1150.0	(.219, .804)	(.348, .060)	(-.534, .707)
1152.0	(.247, .791)	(.350, .053)	(-.521, .713)
1154.0	(.276, .776)	(.351, .045)	(-.506, .720)
1156.0	(.306, .759)	(.351, .037)	(-.491, .726)
1158.0	(.336, .740)	(.350, .028)	(-.475, .733)
1160.0	(.367, .719)	(.348, .020)	(-.457, .740)
1162.0	(.398, .696)	(.345, .011)	(-.439, .747)
1164.0	(.430, .670)	(.340, .003)	(-.418, .754)
1166.0	(.462, .641)	(.334, -.005)	(-.396, .762)
1168.0	(.493, .609)	(.326, -.012)	(-.372, .769)
1170.0	(.525, .573)	(.316, -.018)	(-.345, .776)
1172.0	(.556, .534)	(.304, -.023)	(-.316, .783)
1174.0	(.586, .489)	(.290, -.026)	(-.283, .789)
1176.0	(.614, .441)	(.273, -.026)	(-.247, .793)
1178.0	(.640, .386)	(.255, -.022)	(-.206, .795)
1180.0	(.662, .327)	(.235, -.014)	(-.161, .795)
1182.0	(.678, .262)	(.214, .000)	(-.112, .789)
1184.0	(.688, .191)	(.195, .021)	(-.057, .778)
1186.0	(.689, .116)	(.177, .049)	(.001, .759)
1188.0	(.679, .039)	(.164, .085)	(.061, .729)
1190.0	(.657, -.039)	(.159, .129)	(.122, .688)
1192.0	(.621, -.113)	(.164, .179)	(.179, .634)
1194.0	(.573, -.180)	(.183, .228)	(.229, .567)
1196.0	(.515, -.236)	(.216, .277)	(.267, .489)
1198.0	(.451, -.277)	(.262, .319)	(.291, .404)
1200.0	(.385, -.303)	(.320, .350)	(.298, .317)
1202.0	(.322, -.315)	(.384, .366)	(.290, .233)
1204.0	(.266, -.316)	(.451, .371)	(.268, .155)
1206.0	(.219, -.310)	(.516, .361)	(.236, .086)
1208.0	(.182, -.299)	(.576, .339)	(.197, .028)
1210.0	(.153, -.287)	(.629, .309)	(.155, -.020)
1212.0	(.132, -.275)	(.674, .272)	(.112, -.059)
1214.0	(.116, -.267)	(.711, .231)	(.070, -.091)
1216.0	(.105, -.261)	(.741, .188)	(.030, -.116)
1218.0	(.096, -.258)	(.765, .144)	(-.009, -.136)
1220.0	(.089, -.259)	(.782, .100)	(-.045, -.152)
1222.0	(.083, -.262)	(.794, .057)	(-.078, -.165)
1224.0	(.076, -.268)	(.802, .015)	(-.109, -.176)
1226.0	(.070, -.276)	(.806, -.025)	(-.138, -.185)
1228.0	(.062, -.286)	(.807, -.064)	(-.166, -.193)
1230.0	(.054, -.297)	(.804, -.101)	(-.192, -.199)
1232.0	(.045, -.309)	(.800, -.136)	(-.216, -.205)

In this case, the s-parameters of the unloaded two-port are listed.

1234.0	(.034, -.321)	(.793, -.169)	(-.239, -.210)
1236.0	(.023, -.334)	(.784, -.201)	(-.261, -.214)
1238.0	(.010, -.347)	(.774, -.230)	(-.282, -.217)
1240.0	(-.004, -.360)	(.763, -.258)	(-.302, -.220)
1242.0	(-.019, -.372)	(.750, -.285)	(-.322, -.223)
1244.0	(-.035, -.384)	(.736, -.309)	(-.341, -.225)
1246.0	(-.052, -.396)	(.722, -.332)	(-.359, -.227)
1248.0	(-.070, -.407)	(.707, -.354)	(-.377, -.229)
1250.0	(-.088, -.417)	(.691, -.374)	(-.394, -.230)
1252.0	(-.107, -.426)	(.675, -.392)	(-.411, -.230)
1254.0	(-.126, -.435)	(.659, -.409)	(-.426, -.231)
1256.0	(-.146, -.442)	(.642, -.425)	(-.443, -.231)
1258.0	(-.166, -.449)	(.626, -.440)	(-.459, -.230)
1260.0	(-.186, -.455)	(.609, -.453)	(-.474, -.229)
1262.0	(-.206, -.460)	(.592, -.466)	(-.489, -.228)
1264.0	(-.227, -.464)	(.575, -.477)	(-.503, -.227)
1266.0	(-.247, -.467)	(.558, -.487)	(-.517, -.225)
1268.0	(-.267, -.469)	(.541, -.496)	(-.531, -.223)
1270.0	(-.287, -.471)	(.525, -.505)	(-.544, -.221)

```
T W O   P O R T   R E C T A N G U L A R   M I C R O S T R I P
- - -   - - - -   - - - - - - - - - - -   - - - - - - - - - -

DIMENSIONS (A X B X T) ....................... ( 7.62 X  7.80 X  .15) CM
FEED DATA: (1) WIDTH ........................   .25 C
           (2) PONT ONE ..................... ( 1.00, 1.00) CM
           (3) PONT TWO ..................... ( 1.00, 3.90) CM
LOAD DESCRIPTIONS ........................... CAPACITIVE LOAD: C =  .14E+01
ELECTRICAL PARAMETERS: (1) DIELECTRIC ....... 2.62
                       (2) LOSS TANGENT ..... .00100
                       (3) CONDUCTIVITY ..... 270.0 KMHUS/CM
CENTER FREQUENCY ............................ 1194.0 MHZ
FREQUENCY INCREMENT ......................... 1.0 MHZ
QUALITY FACTOR .............................. 99.8
GAIN ........................................ 6.3 DB
DATE/TIME ................................... 80/03/11. 11.53.52.
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FREQUENC (MHZ)	Z
1170.0	(31.37, 124.99)
1171.0	(34.48, 129.74)
1172.0	(38.07, 134.93)
1173.0	(42.24, 140.45)
1174.0	(47.10, 146.37)
1175.0	(52.83, 152.71)
1176.0	(59.68, 159.46)
1177.0	(67.68, 166.58)
1178.0	(77.38, 173.98)
1179.0	(89.08, 181.48)
1180.0	(103.26, 188.73)
1181.0	(120.42, 195.23)
1182.0	(141.09, 200.08)
1183.0	(165.47, 201.65)
1184.0	(193.37, 198.22)
1185.0	(223.35, 187.40)
1186.0	(253.09, 167.28)
1187.0	(275.51, 137.83)
1188.0	(288.31, 102.24)
1189.0	(288.62, 66.52)
1190.0	(278.58, 36.80)
1191.0	(263.22, 16.47)
1192.0	(247.83, 5.50)
1193.0	(236.26, 1.64)
1194.0	(230.60, 1.77)
1195.0	(231.63, 2.65)
1196.0	(239.01, 1.00)
1197.0	(251.19, -6.39)
1198.0	(264.07, -22.17)
1199.0	(273.20, -47.23)
1200.0	(277.05, -79.26)
1201.0	(267.21, -112.79)
1202.0	(246.75, -141.68)
1203.0	(219.07, -165.11)
1204.0	(191.26, -173.34)
1205.0	(164.24, -177.58)
1206.0	(140.41, -176.45)
1207.0	(120.20, -172.11)
1208.0	(103.36, -165.99)
1209.0	(89.44, -159.04)
1210.0	(77.95, -151.82)

In this case, the input impedance of the capacitively loaded two-port is given under "Z."

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